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THE DELAWARE RIVER BRIDGE BETWEEN PHILADELPHIA AND CAMDEN.*

BY

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THE Delaware River Bridge will of necessity be a long span structure. It must present no obstacles to navigation within the harbor of Philadelphia. The War Department would not sanction any bridge within the port limits which would require piers to be placed between harbor lines, and justly so, for any obstruction between those lines would be very objectionable and might seriously interfere with the future development of the harbor.

When the Board of Engineers appointed by the Delaware River Bridge Joint Commission on September 24, 1920, began its studies, it at once became apparent that a span of not less than 1750 feet between centres of supports would be required, irrespective of its location. The location was limited by the city limits of the two cities which the bridge is to connect. A further limitation was placed by the Act of Congress of February 15, 1921, fixing the limits at Green Street, Philadelphia, on the north, and South Street on the south, to points approximately opposite in Camden.

* Presented at the stated meeting of the Institute held Wednesday, October 19, 1921.

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In a paper presented before this Institute in 1913, I stated that suitable types of spans for various span lengths are:

For spans up to 750 feet.....	Simple spans
For spans from 650 feet to 2000 feet.	Cantilever spans with suspended span
For spans from 1500 feet to 4000 feet.	Cable suspension spans

I pointed out that the above limits overlap and that local conditions should be considered in deciding whether a span between 650 and 750 feet should be a simple span or a cantilever, or whether a span between 1500 feet and 2000 feet should be a cantilever or a suspension span. And I referred to certain objections, under certain conditions, to the suspension type. In a railroad bridge, unless it is to carry a large number of tracks, the span may be loaded to its full capacity on one part of the continuous structure, while at the same time there may not be any load on the other. Such conditions produce in a suspension span large wavelike deflections which are objectionable and tend to cause undue wear in the many connections. But in a highway bridge, the loads are always fairly well distributed over its entire length, and a condition of such unequal loading as may occur in a railway bridge can only be produced artificially. The greater the capacity of the highway bridge, or, in other words, the more lines of travel provided for, the more evenly will the simultaneous loading be distributed. The Delaware River Bridge is a highway bridge. It will have six lines of vehicular traffic and four lines of rail traffic for street car and rapid transit purposes. All together, not counting the sidewalks, ten lines of travel.

The distance between Philadelphia and Camden harbor lines varies from about 1690 feet at Callowhill Street, Philadelphia, to 1763 feet at South Street, Philadelphia, or a total variation of about 73 feet. Since the length of span would be between 1500 feet and 2000 feet the type of span, whether cantilever or suspension, could not be determined without a thorough investigation of both types. A span of 1750 feet was assumed for this investigation. The loading was assumed to be as follows:

Two lines rapid transit tracks, each at 2000 lbs. per lin. ft.	4,000 lbs.
Two lines surface cars, each at 1500 lbs. per lin. ft.	3,000 lbs.
57 ft. roadway at 70 lbs. per sq. ft.	3,990 lbs.
20 ft. walkway at 50 lbs. per sq. ft.	1,000 lbs.
Total per lin. ft.	11,990 lbs.

Twelve thousand lbs. per lineal foot of bridge is therefore taken as live load. This loading will be referred to later. Given the span length and the loading, two designs were prepared, in sufficient detail for a close estimate—one a suspension bridge, with wire cables, and the other a cantilever bridge with a suspended span. Everything else being equal, the cost of the cantilever type was shown to be nearly $2,000,000, or about 13 per cent. more than the suspension type. In this comparison, the cost of the main structure only has been considered. This great difference in cost would no doubt have been sufficient to throw the balance in favor of the suspension design, but there were other considerations, such as the more graceful lines, the greater safety during construction, and the fact that it lends itself to a greater subdivision of contracts. And all these were additional factors in leading the Board of Engineers to recommend the suspension type.

This subdivision of contracts means that in the suspension design, contracts may be let in sequence as follows:

First—the main piers,
Second—the anchorages,
Third—the steel towers,
Fourth—the cables and suspenders,
Fifth—the stiffening trusses and floor.

In the cantilever design, the superstructure would have to be let in one contract of nearly $10,000,000. This, with the funds thus far appropriated, would be impossible, and the superstructure contract would have to wait for the next meeting of the Pennsylvania Legislature, two years or more hence, before it could be awarded. The delay which such waiting would involve is evident.

The design adopted contemplates steel towers placed on granite piers which will be founded on rock by pneumatic process. The

caissons will be 70 feet by 143 feet in their horizontal dimensions and 40 feet high. They will be filled with concrete and surmounted by crib work, also filled with solid concrete. The granite facing will extend 2 feet 6 inches below low water. The borings thus far completed show the rock to be about 62 feet on the Philadelphia side and 86 feet on the Camden side below mean high water. (Fig. 1.)

We have all admired the massive masonry towers of the Brooklyn Bridge. There have also been other suspension bridges built with masonry towers. Such construction requires that the saddles on top of the towers which carry the cables be placed on rollers to accommodate the motion of the cable due to changes in loading and temperature.

Reliance then must be placed on the rollers to move freely, or the masonry tower will bend. In the Brooklyn Bridge rollers have been provided under the cable saddles. Prior to 1907 intermittent and jerky displacements of the saddles had been observed. These had the tendency to disturb the interadjustment of the cables, stays and suspenders. Rigid traffic regulations were introduced in 1907 requiring certain spacing of all trains. Since then no motion of the saddles on rollers has been observed. But motion exists, and since the saddles do not move the towers bend. While a small range of bending in masonry towers is not harmful it is not desirable because it introduces an unknown element, namely, the elasticity and resistance to bending of masonry.

In the Williamsburg Bridge the masonry towers have been replaced by steel towers which, however, were made rigid. Here also the motion of saddles was intended to take place by means of rollers. These move at times, but the frictional resistance is great and is a disturbing element.

While no one wishes to deny that at the time the Brooklyn Bridge was built, it was a masterpiece of engineering, yet since then the engineering science has not stood still. It has been recognized in the design of the Manhattan Bridge that rollers on top of the towers should be eliminated, or, in other words, the cable should be fixed to the tower tops. This can only be accomplished by making the tower flexible or by providing it with a hinge at the bottom. Since it is perfectly feasible to ascertain the amplitude or range of the motion required at the top of the tower, and since the resulting stresses in a steel flexible tower fixed at the bottom are

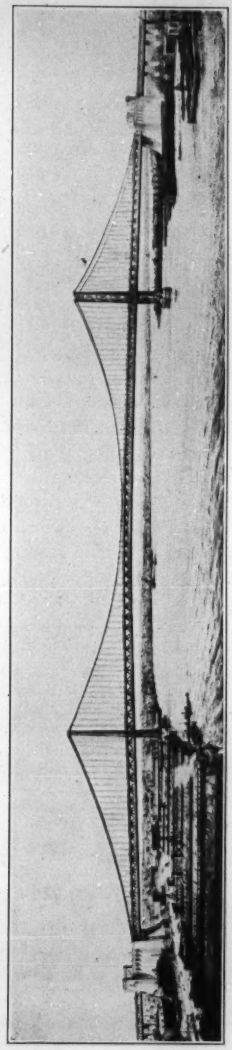


FIG. 1. General View.

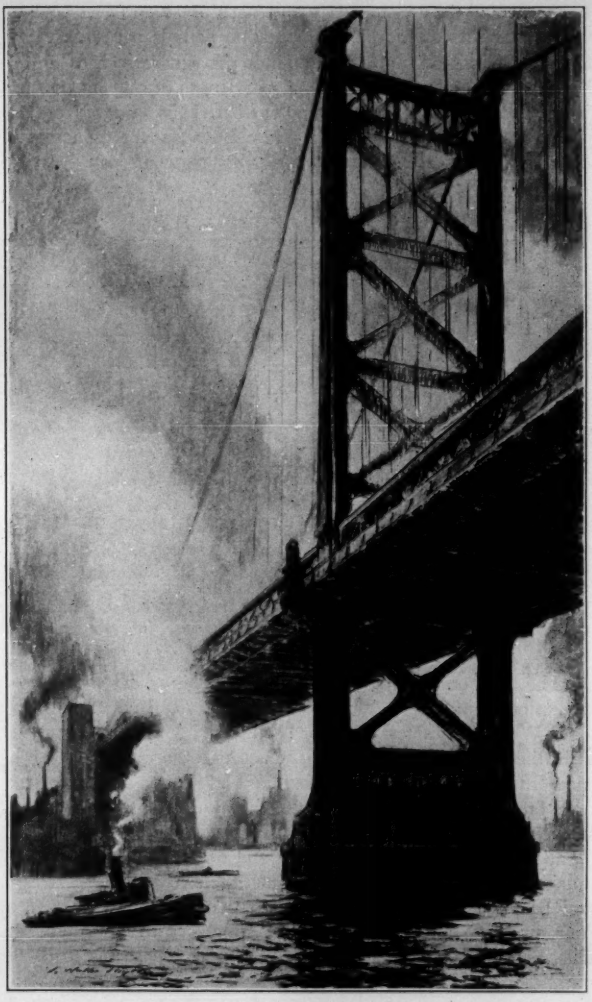
easily analyzed, such a tower has been given preference to one with a bottom hinge, as eliminating a complication in the details as well as the wear which would necessarily occur on a hinge, were it to act as such.

The elastic tower, then, provides a solution which obviates the uncertain action of the rollers on top and of a hinge at the bottom. To be elastic, the towers must be slender, so that they form a marked contrast to the massive towers of masonry of the Brooklyn or the Buda-Pesth Bridges. The slenderness of the towers of the Delaware River Bridge has received criticism from some sources and also favorable comment from others. We all know that our æsthetic sense is a matter of education. We have been educated on the Brooklyn Bridge. But a logical construction must of necessity be harmonious, and a departure from traditions is not always in the wrong direction. It is quite possible that when we become accustomed to the more graceful lines of flexible steel towers, which are certainly more in harmony with the slimness of the cables, we shall look upon the old-fashioned masonry towers as monuments, true, but rather as pioneering in the art of building suspension bridges. The total bending at the top of the towers as now designed for the Delaware River Bridge will be 21¼ inches toward the main span and 15½ inches toward the shore under extreme conditions of loading and temperature. (Fig. 2.)

The anchorages of a suspension bridge are probably more difficult to design than any other part of the structure. This is due to the fact that they must remain immovable under the uplifting and horizontal sliding efforts to which they are subjected. The character of the soil and the depth at which solid rock is found are the main factors in determining the design of the foundations to support these large blocks of masonry in which the cables take hold. At the time of writing this paper, the borings have been completed only partly, and the design of the foundations is therefore as yet unfinished. (Fig. 3.)

We now come to the backbone of the structure—the cables. Each of the three New York suspension bridges has been built with four cables. The Delaware River Bridge will have two only, but of rather unusual dimensions. Each cable will be built of 16,500 number six wires, and will be 30 inches in diameter. It is also intended to prepare a complete design of a stiffened eye-bar type. In this connection it may be of interest to note that while a wire hanging

FIG. 2.



Tower and Main Pier.

free with the same ratio of sag to span length as the Delaware River Bridge would have to have a span length of 32,000 feet before it would reach its elastic limit of 140,000 pounds per square inch, the elastic limit of say 85,000 pounds per square inch of an eye-bar chain would be reached with a span length of only 15,000 feet. These figures are for the wire and eye-bar chain hanging free supporting their own weight only. They show that the economic advantage of wire cables increases with the length of span.

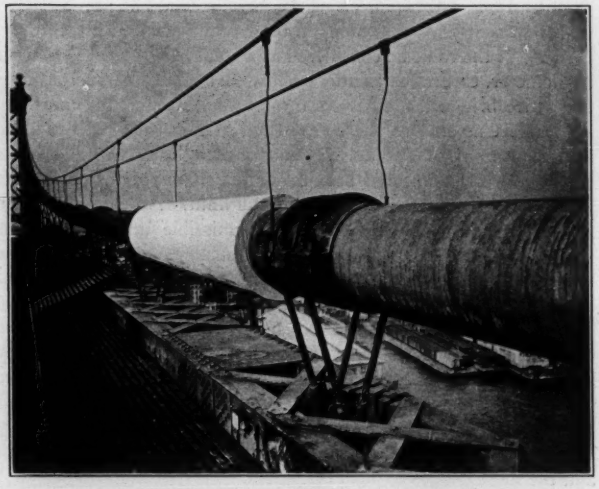
FIG. 3.

Anchorage pier.

The chief purpose of reducing the number of cables to two is to eliminate as far as possible the uncertainty of distribution of live load. With four cables, the floor beams may either be continuous, as in the Manhattan Bridge (in which case they must be strong enough to take up the unequal loading of the four stiffening trusses), or they must be hinged at the two middle stiffening trusses. In the first instance, they act as transverse stiffening girders, complicating the distribution of loading, and adding more assumptions, thus spreading the limits within which the calculations of stresses may be accepted as exact. The use of two cables only, instead of four or more, admits of a greater simplicity of design of details, as well as of the structure as a whole. It seems to be the

more direct and logical solution. In my opinion simplicity and directness should be the underlying principles of all engineering structures. This does not mean that these structures should not be made beautiful in their proportions and lines, or that some consideration should not be given to ornamentation, as long as such ornamentation is also logical and in harmony with the logical

FIG. 4.



Comparative sizes of the Manhattan and Delaware River Bridge cables.

engineering structure. Neither does this mean that four, six or more cables should not be used in cases where conditions require it.

Thirty-inch cables have not yet been built. The Brooklyn Bridge cables are 15¾ inches in diameter, those of the Williamsburg Bridge, 18¾ inches and those of the Manhattan Bridge 20½ inches in diameter. There is therefore a marked increase in the size of cables of the Delaware River Bridge over those of the New York bridges. (Fig. 4.) This increase may appear somewhat bold but a close analysis of the matter shows that it only means an increase in scale without presenting any unusual difficulties of con-

struction or uncertainties of efficiency. Three main questions present themselves with a cable of this great size.

(1) The cable deflects or sags under load and temperature, causing a certain amount of bending over the tower and anchorage saddles. This results in secondary stresses. Are these stresses not excessive?

(2) What will be the efficiency of the cable as a whole, comparing it with the strength of individual wires?

(3) How will corrosion of the interior wires be prevented?

Answering these questions in their order, we find that:

(1) If the cable be considered as a solid bar of steel, 30 inches in diameter, careful calculations show that under the condition of the entire bridge loaded to its utmost capacity and the most unfavorable temperature the co-existing stresses will reach a total maximum of 79,800 pounds per square inch. Our working stress for congested loading has been taken at 72,500 pounds per square inch, or less than one-half of the elastic limit. An excess of 7300 pounds, or about 10 per cent., is permissible under conditions which are not liable to happen once in many years. But the cable is not a solid steel bar; but is made up of a multiple of wires. That stress will therefore be considerably less, and will only occur in the top and bottom wires, diminishing toward the centre of the cable where it becomes zero. Besides, it is easily provided for by an addition of material if found necessary. Then, again, the loading necessary to produce the above result will never occur. It can only be applied artificially, since it would require absolutely no load on certain portions of roadways, tracks and sidewalks, and the most congested load on others.

(2) A single wire hung from the towers with a sag of 200 feet in the centre of a 1750 foot span will be subjected to a tension due to its own weight of 210 pounds, or 7000 pounds per square inch. A variation of 1.1 inches in sag will increase or decrease this stress by 1000 pounds per square inch. By the use of carefully adjusted guide wires, strung to the exact sag required at a given temperature, all wires are set to exactly the same sag and therefore are subjected to the same initial tension. This tension is sufficient to keep them taut without kinks of any kind. The longer the span, the greater the initial tension in these wires. This initial tension is not disturbed by tying all the wires into strands or by wrapping the strands with wire into one cable. So that after

the cable is completed and hanging free, every wire is stressed to the same amount. We now hang from it the stiffening trusses, floor, etc., and send live load over the bridge—all of which produces an elongation in the cable as a whole, and it is obvious that each wire must elongate by the corresponding amount. As we all know, the stress for a given elongation is proportional to the modulus of elasticity. A series of experiments has shown that the moduli vary from 26,500,000 to 27,800,000, a variation of about 5 per cent. The stresses in the individual wires therefore cannot vary among them more than 5 per cent. This means that if the cable is stressed as a whole to 70,000 pounds per square inch, some wires may be stressed to 68,250 pounds and some to 71,750 pounds, but no wire would be stressed above 73,500 pounds per square inch.

The only factor which may tend to reduce the efficiency of the cable is the transverse pressure which the wires receive at the saddles and at the suspension points, where a transverse compression is exerted by the special castings which carry the suspender rods or cables. It is proposed to make special tests to determine how much, if at all, the strength of wires is affected by such a transverse pressure. We can only draw an inference from the action of ordinary steel cables or ropes working on sheaves, that the effect will not be material.

(3) The Brooklyn Bridge cables have been in service for 47 years. The wires of the cables were galvanized. Inspection made by the Plant and Structure Department of New York, by prying the cables open with wedges, shows that there has been no deterioration of the wires by rust or otherwise. There is no reason why these cables should not last indefinitely. The wires of the Delaware River Bridge will also be galvanized.

The loss in tensile strength of the wire due to the galvanizing is about 7 per cent.

From the cables are suspended the stiffening trusses. Their necessity has been recognized in the construction of the early suspension bridges. They serve the purpose which their name implies, that is to reduce the wave motion of the main cables under unequally distributed loads. They may be provided with hinges at the centre of the main span or with slip joints at one or more points which permit longitudinal motion, but may transmit bending, or they may be continuous over the entire main span, with pro-

vision for expansion at the towers. In the Delaware River Bridge the stiffening truss is made continuous for each span, and expansion is provided for at the towers. This has the advantage of allowing the stiffening trusses to expand in the direction of the increasing length of suspenders. The greater the motion due to the expansion the greater the length of the suspenders.

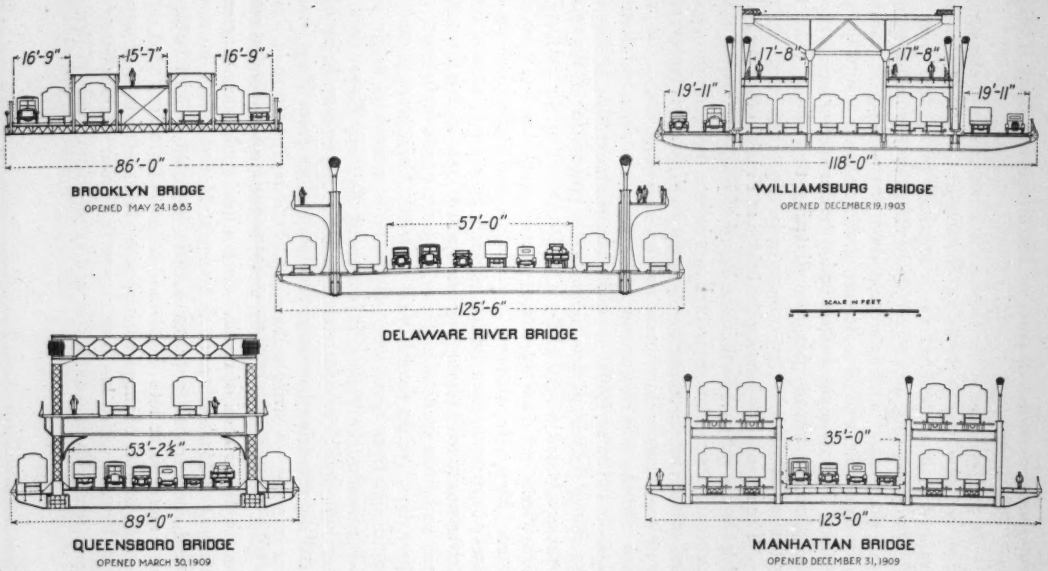
The arrangement of the side spans may either consist of viaducts independent of the cables, the latter simply connecting to the anchorage at a convenient distance, as in the Williamsburg Bridge, or they may consist of stiffening trusses suspended from the cables as in the Manhattan Bridge. The latter system has been adopted in the Delaware River Bridge, as more economical and presenting a better appearance.

The deck of the bridge is arranged to provide a single roadway for vehicles, 57 feet wide between curbs, two street car tracks and two rapid transit cars, all on approximately the same level. Above the rapid transit tracks will be two sidewalks, each 10 feet wide. The single roadway provides for six lines of vehicular traffic. It is evident that the capacity of a single roadway is much greater than that of two roadways of one-half the width. At certain hours of the day, the traffic will usually be much heavier in one direction than in the other. A single roadway of six-line width will permit four lines to go in one direction, the smaller return traffic taking only two lines. This could not be done if there were two separate roadways of three-line width only. This feature of the design was considered of vital importance in planning the arrangement of the deck. (Fig. 5.)

There are only two bridges in New York which have a single roadway, namely, the Manhattan Bridge, with a roadway 35 feet wide, and the Queensboro Bridge, with a roadway 53 feet 2½ inches wide. The 57-foot roadway of the Delaware River Bridge is only 3 feet narrower than Market Street, in Philadelphia. We have seen that the live load has been assumed at 12,000 pounds per lineal foot of bridge. This corresponds to the maximum or congested loading, and in order to reach that figure, the roadways would have to be loaded with automobiles and heavy trucks in close contact, the four tracks loaded with continuous lines of heavy type cars filled to capacity with passengers, and the sidewalks crowded at the rate of one grown person to every 3 square feet.

Such a loading is so improbable as to be almost impossible,

FIG. 5.



Comparative cross-sections of five large bridges.

but should it occur, all parts of the bridge will carry it within very safe limits.

In the Delaware River Bridge the arrangement of the surface lines and rapid transit tracks was the subject of much study. It is planned to keep the entrance or approach plazas free from car tracks of any sort, also to avoid objectionable elevated structures near the plazas. This is accomplished by causing such tracks to ascend and descend at a steeper grade than the roadways and placing their terminals or connections under the surface grade of the plaza, in Philadelphia, and diverting them away from the plaza in Camden.

The reasons for locating the bridge at Franklin Square, Philadelphia, are fully set forth in the Board of Engineers' report to the Delaware River Bridge Joint Commission, dated June 9, 1921, and printed for distribution. It might be of interest, however, to state here how the Board went about to determine one of the principle factors, that of the centre of gravity of origin and destination of vehicular traffic on each side of the river. It was not possible in the limited time allotted to the preparation of the report to take a census of the traffic at various times of the year. The Board therefore chose three representative week days in December, 1920. Men were stationed in relays, day and night, at all the six lines of ferries between Philadelphia and New Jersey points. Each driver was asked to state where he started from, giving town, district and street corners, and also the point of his destination. In three days, 16,269 records were secured. These were plotted on maps, and from them were obtained the centres of origin and destination of the traffic. It is believed that fully 80 per cent. of the traffic was thus represented, the other 20 per cent. being of a kind not occurring in winter, such as produce from New Jersey, for instance. A straight line drawn between the centre in Philadelphia and the one in Camden would be the most economical route for the 80 per cent. of traffic. Such a line would come very near the foot of Market Street. A bridge at Market Street, however, could not be considered because, first, it would be inadvisable to turn more traffic into the already congested Market Street, and, second, because of the prohibitive cost of real estate to be acquired. The location which has been chosen is as near Market Street as consistent with reasonable cost and as physical conditions permit.

AERONAUTIC RESEARCH.*

BY

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Professor of Physics, The Johns Hopkins University, Baltimore, Maryland; Chairman Executive Committee National Advisory Committee for Aeronautics.
Member of the Institute.

PROGRESS in the navigation of the air is being made constantly along two quite distinct and independent lines; one is the art of flying and the other is the science of flight. To this last is given the name *aeronautics;* and by an aeronautical investigation is meant a research which has a direct bearing upon our knowledge of the properties of solid bodies immersed in a stream of air or moving through the air. We wish to know the forces and moments acting upon such solid bodies; how these vary with the shape and characteristics of the bodies, and how they are affected if the velocity of the air is changed. Another important inquiry refers to the stability of the solid body when in flight; if the attitude of the body is changed by some gust or otherwise, does it tend to return to its previous attitude, or on the contrary does it continue to depart more and more from its original attitude? The question is like that referring to a body balanced on a table. If it is pushed slightly, will it simply oscillate to and fro, or will it turn over? These matters and similar ones make up the subject of aeronautics; and in order to investigate them the same methods must be applied as in any department of physics.

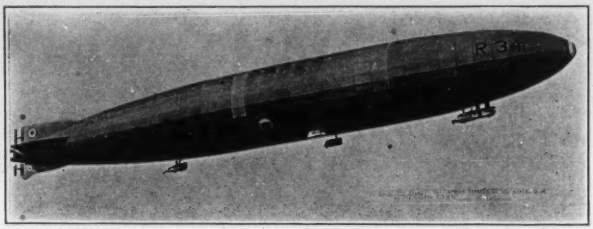
Experiments must be performed; a theory is evolved; deductions are made from the theory and tested by experiment; the theory is modified and improved, etc. During all the process knowledge is being gained, and the facts being made known help the designer of aircraft to make improvements in speed, in carrying power, in safety, in stability.

One most important fact should be emphasized, and this is that without the series of scientific studies just outlined not only would flight itself have been impossible, but also all progress in the art would cease. Scientific investigation forms the most important feature of aviation, and it can be conducted only by trained

* Presented at the meeting of the Section of Physics and Chemistry held Thursday, October 6, 1921.

students. The best pilot in the world may know very little about the scientific principles underlying flight, and he would therefore be unable to make any marked improvements in his machine. Aeronautics is in no sense a function of an engineer or constructor or aviator, it is a branch of pure science. Those countries have developed the best airships and airplanes which have devoted the most thought, time and money to the underlying scientific studies. When the physical facts are known, the engineer can design his aircraft, the constructor can make it, and the trained man can fly it; but the foundation stone is the store of knowledge obtained by the scientist.

FIG. 1.



Airship, filled with hydrogen. Engines and propellers; elevators and rudder; stabilizing surfaces.

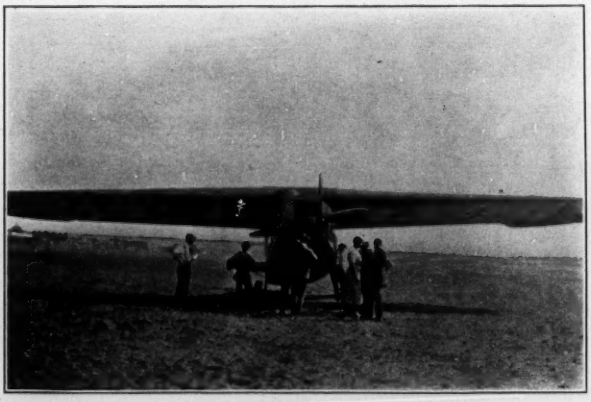
Before describing the types of investigations in progress in aeronautics and the methods pursued, it may be interesting to see some illustrations of the two types of aircraft now in use: The airship and the airplane. If I had time, I would like very much to say something about the helicopter, a type of aircraft to which we have given a name before constructing one. Up to the present no such machine, worthy of the name, has been made; but beyond a doubt one will be constructed, and in the near future.

An airship owes its flying power to the fact that it is made "lighter than air" by being filled with a gas lighter than air. Hydrogen is the gas always used, although helium may be. The lifting power of the latter gas is about four-fifths of that of hydrogen. As the airship moves through the air, it meets with opposition as the air flows along its surface. Forces are required to move the control surfaces, *i.e.*, the rudders and elevators. We

FIG. 2.

Airplane. Wings, fuselage, ailerons, elevator, rudder, etc.

FIG. 3.



Fokker F. III. Commercial monoplane.

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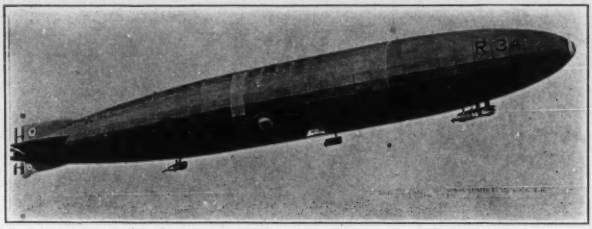

Airship, filled with hydrogen. Engines and propellers; elevators and rudder; stabilizing surfaces.

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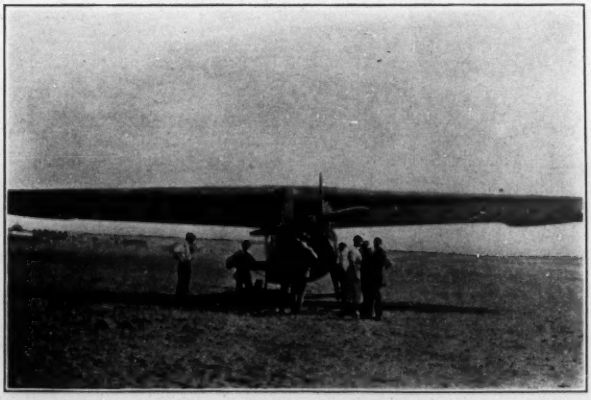
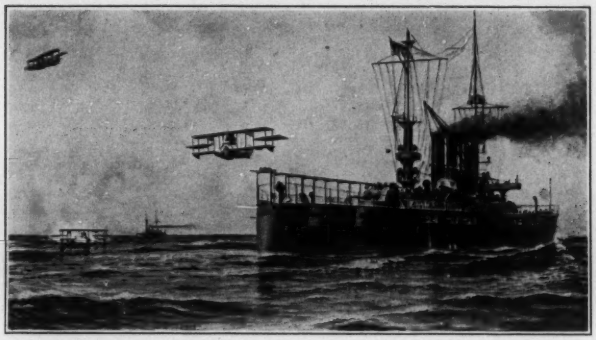


Fokker F. III. Commercial monoplane.

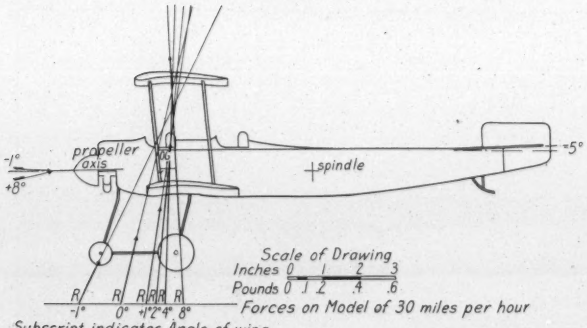
must determine these forces, and must investigate the changes in them as we change the shape of the airship, *e.g.*, its length or its cross-section. A great deal may be learned by studying theo-

FIG. 4.



Airplane carrier. Seaplanes in flight.

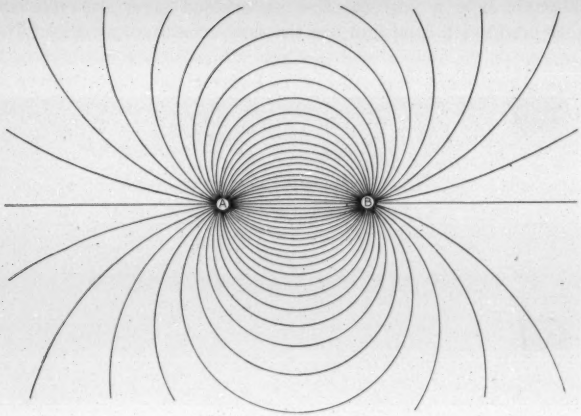
FIG. 5.


propeller axis
spindle
-1°
+8°
+5°
Scale of Drawing
Inches 0 1 2 3
Pounds 0 .1 .2 .4 .6
R R R R R
-1° 0° +1° 2° 4° 8°
Forces on Model of 30 miles per hour
Subscript indicates Angle of wing chord to wind for corresponding Force, R

Drawing showing parts of an airplane model and the force-diagram.

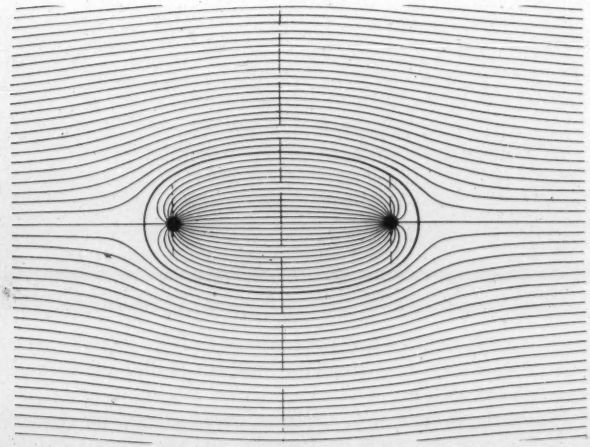
retically the way in which air flows around a solid body shaped more or less like an airship. A most interesting mode of attack on this problem was devised by Admiral Taylor of our Navy, and

FIG. 6.



Combination of source and sink.

FIG. 7.



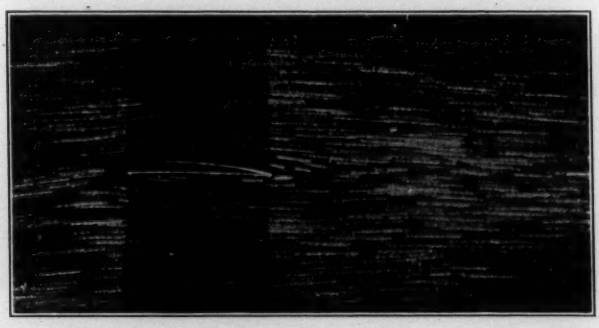
Air flow due to superposing a uniform rectilinear flow upon a combination of source and sink.

was applied by him to the design of ocean vessels. The drawings illustrate how a uniform flow superposed upon a source and sink produces a condition like the flow around an airship. This

FIG. 8.

Eddying flow past an aerofoil.

FIG. 9.



Stream-line flow past an aerofoil.

type of flow may then be studied mathematically; the pressures may be deduced, etc.

Similarly, in the case of airplanes, we must know the character of airflow past the struts, the fuselage and the wings. It is the difference in the pressure on the two sides of a wing that produces

the upward force required to support the machine. The figures illustrate the type of flow around an aerofoil.

Great progress has been made in recent years by Prandtl and other German physicists by showing how a flow of air around an aerofoil could be produced in an ideal frictionless gas similar to that observed in air, by imagining vortices or whirls in the gas. The method is not unlike that mentioned above as useful in the case of airships, only vortices are used in place of sources and sinks. Following this process Prandtl and his associates have shown how one could calculate the influence of one wing of a

FIG. 10.

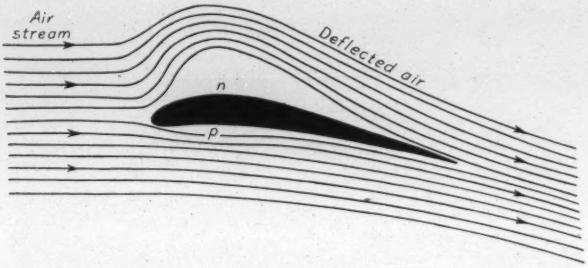


Diagram of flow past an aerofoil showing an increased pressure below and a decreased one above.

biplane upon the other; so that if the behavior of one wing is known that of two may be deduced; and they have proceeded much further and made aeronautics into a beautiful theoretical science.

But in the end the function of aeronautic research is obviously to learn all there is to be known about the forces acting on an aerofoil or wing. How can this be done? It is not possible to make actual airplanes of various types and test them, nor would this help us much if it were practicable. We must actually measure the forces involved in any one case, and must vary our conditions in every conceivable way, but in a systematic manner. There are several methods open to us. One is to make a model of a wing, say, as nearly full size as possible, suspend it by wires 30 feet or more below an airplane which can carry it in flight, and then, by inserting measuring instruments in the wires study the forces under varying conditions. This method is being used with marked success at Langley Field, near Old Point Comfort, Virginia, by

the staff of the National Advisory Committee for Aeronautics. It is called the " free-flight method."

A second method is to make a small model of a wing or a fuselage or an entire machine, say one twenty-fifth the size of the

FIG. 11.

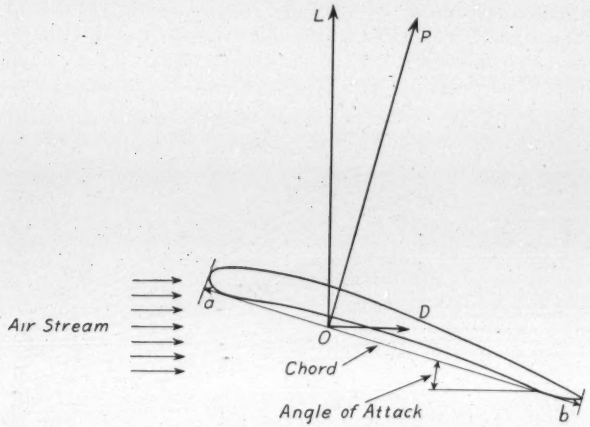


Diagram illustrating forces acting on an aerofoil.

FIG. 12.

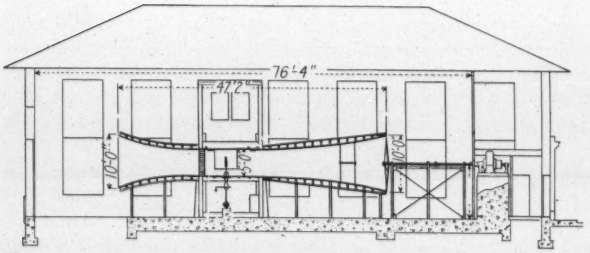


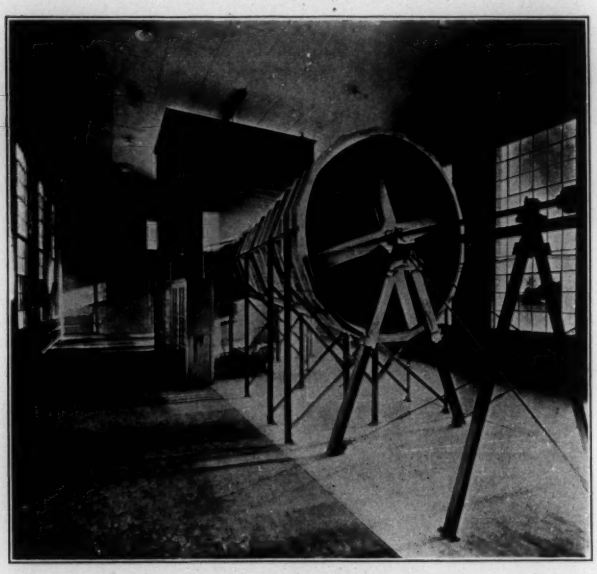
Diagram of wind-tunnel in its house.

actual part, and then to investigate the forces acting on it when it is placed in a rapidly moving stream of air. This is known as the wind-tunnel method, and is now in general use in all countries. England has ten or more such tunnels, France has several, Ger-

many has a large number, etc. In this country there are twelve, and more are being made.

Other methods have been used in the past, but are no longer. Langley attached his models to one end of a long arm which could be made to revolve rapidly in a horizontal plane. Others have

FIG. 13.



Exterior of tunnel, from exit end.

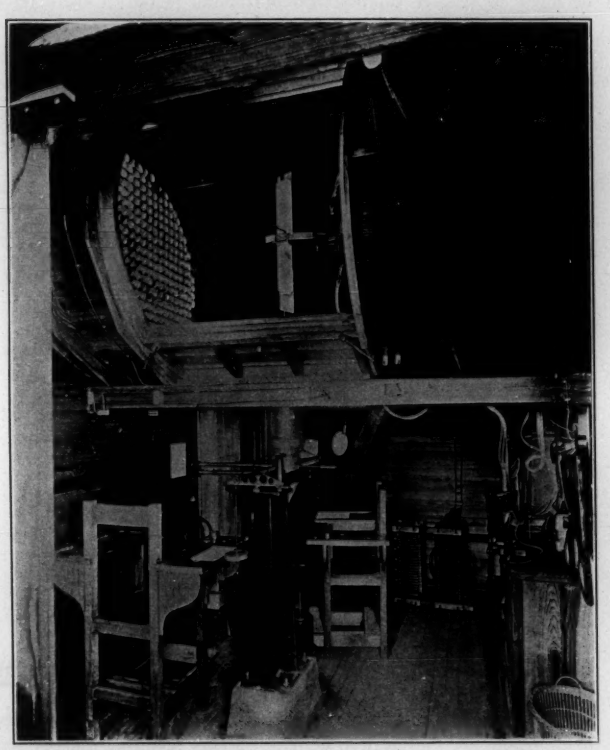
studied models of different shapes by dropping them from heights inside buildings, so as to avoid wind.

Owing to the importance of wind-tunnels, I will show some photographs of the latest one made in this country, that of the National Advisory Committee for Aeronautics at the Langley Memorial Laboratory, Langley Field, Virginia.

Investigators in these different laboratories all over the world have studied the greatest variety of problems: Forces on models of wings of different shapes at different air velocities, forces on

models of airships, the effect of disturbing elements on these forces, etc. A long series of investigations has been made in particular upon air propellers. The blade of a propeller may be con-

FIG. 14.

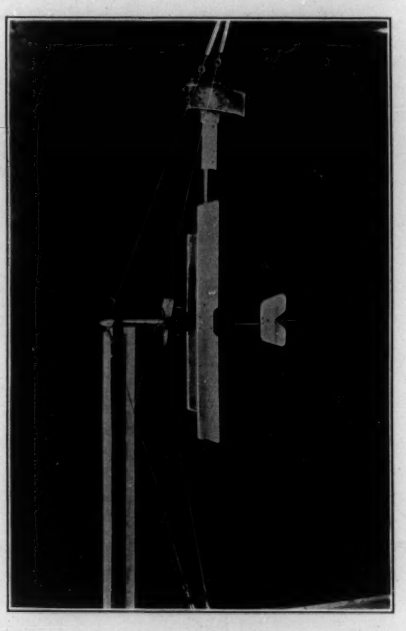


Interior of experimental room and view of model suspended in tunnel.

sidered as made up of a number of separate surfaces; and, when the shaft is rotating, each of these is thought of as an aerofoil moving rapidly through the air. In this way the action of a pro-

peller may be calculated, and the theory may be tested by trying the actual propeller. But there is one all-important difficulty in applying the knowledge thus available to the design of actual aircraft. Is one justified in drawing conclusions as to the properties

FIG. 15.

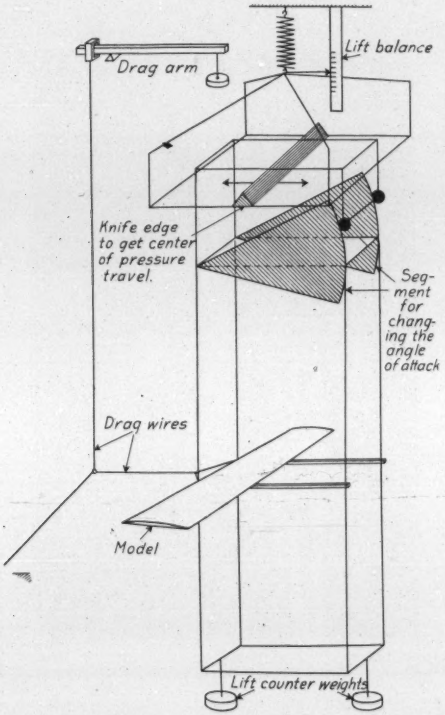


Model of a biplane.

of large bodies from knowledge of the properties of smaller ones? Suppose, for instance, that on comparing two models, on a scale of one twenty-fifth of full size in a wind-tunnel through which the velocity of the airstream is 40 miles per hour, it is found that one model has a greater lift or a less drag than the other, what conclusion could one draw as to the comparative properties of two actual airplane wings in flight at 120 miles per hour? The answer is,

"possibly none." The exact condition in order that results from tests on models may be applied to actual construction is known. This can best be described by discussing what is called in aero-

FIG. 16.

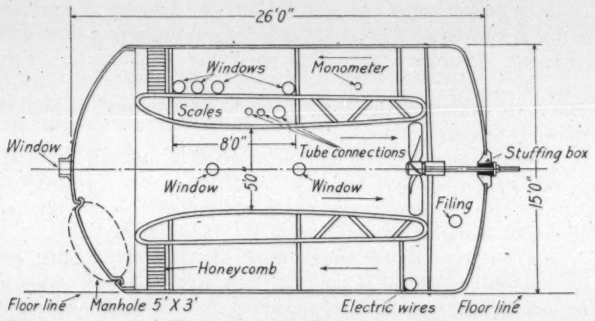


Scheme of the balance used to measure the forces on a model.

dynamics the "Reynolds number." When a body is moving through the air there are two types of forces acting on it: The air exerts a pressure upon it and there is friction between the moving air and the layer of air sticking tight to the solid. It is not difficult to see that the four physical quantities involved in the

aerodynamical action are: The velocity of the air, its density, its viscosity (*i.e.*, measure of the frictional property) and the size of the solid body as given by its length or its thickness. Lord Rayleigh showed many years ago that, if we formed the quantity $\frac{\text{density} \times \text{velocity} \times \text{length}}{\text{viscosity}}$, which is now called the "Reynolds number," we would be justified in saying that the properties observed in any experiment would also be found to be the same for any other experiment having the same Reynolds number. It is seen by looking at the definition of this number that we can have the same Reynolds number for a large number of different experi-

FIG. 17.



Compressed air wind-tunnel.

ments. Thus compare an actual airplane in flight at 90 miles per hour say, with a wind-tunnel experiment on a model of one-twentieth scale but having the same velocity of airflow. If the Reynolds number is to be the same for the two cases, it is necessary to increase the density of the air in the wind-tunnel twenty-fold. This shows that if one were to make a wind-tunnel in which the air is compressed to twenty or more atmospheres, experiments on models placed in it would give results immediately applicable to full-sized airplanes. It is perfectly possible, of course, that certain properties studied and observed in ordinary wind-tunnels at atmospheric pressure may hold also for actual airplanes; but one cannot be certain of this until the question is investigated in a compressed air tunnel. In view of the great importance of this matter,

the National Advisory Committee for Aeronautics has designed and has now under construction such a tunnel in which the air may be compressed to 25 atmospheres. When completed, it will be the only one in the world; and it is expected confidently that a great amount of useful information will be obtained.

I have outlined the experimental methods available for aeronautical investigations, and wish now to state briefly some of the more important ones which occupy our thoughts.

1. Every one, the world over, is interested in designing a helicopter; but before this can be done we much have knowledge of the properties of a propeller whose shaft is very oblique to the flight path, and we probably shall have to design a new type of propeller.

2. A greater range of speed for any one airplane is desirable, so that it may attain a great flying speed and yet have a slow landing speed. In order to secure this possibility, modifications of the wing are essential; and the most promising form at the present time is the Handley-Page slotted wing. Much more research is, however, necessary.

3. Great improvements may be expected in reducing the drag, or resistance, of aircraft, and many researches are now in progress as to the effect of putting the engine and propeller in different positions, of changing the position of the fuselage, etc.

4. Over 100 different wing forms have been investigated, but our practical knowledge is far from satisfactory, largely owing to the fact that the tests have been made in different laboratories and at different air velocities. Further, of course, the Reynolds number in all tests has been too small. When the compressed air wind-tunnel at the Langley Memorial Laboratory is finished, we will be able definitely to say what wing is best for any specific purpose.

These are simply illustrations of the type of investigations now engaging the attention of aeronautical laboratories, but they serve, I hope, to make clear how interesting the subject is to the scientist and how important to the designer of aircraft.

CHEMICAL ASPECTS OF VOLCANISM WITH A COLLECTION OF THE ANALYSES OF VOLCANIC GASES.*

BY

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I. INTRODUCTION.

VOLCANOLOGY like other branches of geology is a subject of many phases enlisting the services of many sciences. Chemistry is chiefly concerned with the more active stages.

The peculiar inaccessibility of the active volcano, its remoteness in many cases and the intermittent character of its processes have conspired to limit opportunities of observation and have therefore greatly retarded the progress of the subject. It is as yet hardly entitled to be called a science. The limited opportunities for observation have naturally compelled the student to depend in large measure on the observations of others. Furthermore, it is eminently true of so complex a subject that tentative conclusions arrived at by any special train of reasoning must be examined in the light of many different sciences before they can become generally acceptable. Every contributor to it must therefore be aware of the fragmentary character of his work.

A comprehensive consideration of volcanology in its chemical aspects would include at least a discussion of the magma, of the influence of the composition of lavas and especially the volcanic gases on intrusive and eruptive phenomena, and the part played in these phenomena by chemical energy. Present knowledge permits us to go but a short way along any of these paths.

II. NATURE AND ORIGIN OF THE VOLCANIC GASES.

Chamberlin and Salisbury [1] say: "It is one of the outstanding problems in geology to determine the origin of the volcanic gases." As a first step in the solution of this problem we shall endeavor to determine what the original gases are through a discussion of

* Presented at a meeting of the Section of Physics and Chemistry held Thursday, December 1, 1921.

[1] "Textbook of Geology," vol. i, p. 592. (New York, 1904.)

the constituents of these gaseous mixtures as they occur in the field, their chemical characteristics and the field conditions which may have influenced them.

I. Integrity of the gases studied; possible changes in the composition of original gas mixtures.

(1) *By Addition of Air.*—Volcanic gases as collected in the field generally contain oxygen. In some instances field conditions such as low gas pressure in a vent, or a large surface opening within which gases issue only at certain points, are practically sure to result in atmospheric contamination and some methods of collection necessarily involve admixture of air; but even when the conditions of collection exclude errors from sources of this sort the quantity of oxygen may still be considerable, amounting occasionally to as much as 20 per cent. It is safe to say that this oxygen was not derived from the original magma, for that portion of it which was not retained by combination with ferrous oxide would surely be reduced to a negligible quantity by the combustible gases contained in it—hydrogen, carbon monoxide, etc.—inasmuch as their oxygenated products, water and the dioxide of carbon are only weakly dissociated at the temperatures which molten lavas are known to attain. The oxygen is therefore in all probability exotic, originating presumably in the air which in some way finds access to the gaseous conduits below the surface of the ground. The hypothesis is that air is drawn through pores and crevices of the conduits or fumaroles by the suction of the hot rising gases. The manner of access is difficult if not impossible to prove, but the contamination by air is substantiated by other evidence.

(a) *Significance of the Relations Between the Inert Gases.*—Fumarole gases collected in 1919 in the Katmai region, Alaska, and studied by E. G. Zies [2] and myself, were found to contain nitrogen and argon in very nearly the same proportion to each other that is found in the air. The average percentage of argon in the inert gas was 1.25, while in the atmosphere it is 1.18. The inference was that these constituents of the fumarole gases came chiefly from the air along with oxygen which had been largely, but not entirely, removed by chemical reactions occurring partly outside the fumaroles, and partly in the fumaroles themselves; while the inert nitrogen and argon remained in their original proportions. The highly porous nature of the pumiceous deposit

[2] Unpublished.

in which the Katmai fumaroles occur affords easy access to air and thus partially substantiates the hypothesis.

Our conclusion was the natural, but not the only one. The French scientist, Moureu, has examined with care a large number of natural gases. He states that in all of them the relations of all the inert gases to one another except helium are sensibly the same as they are in the air, and he concludes from his results that these constituents originated in the primordial atmosphere of the globe, and that because of their inert chemical nature they have remained uncombined and in virtually the same proportions to this day. Moureu's [3] investigations were confined chiefly to spring gases and mine gases; only one volcanic gas was included. When we seek further evidence on these relations we find that most recorded analyses of volcanic gases do not include argon. Gautier,[4] in two samples, one from Vesuvius and one from Lago d'Agnano near Naples, found the percentage of argon in the inert gases nearly the same as in the atmosphere. Moissan [5] also, in a gas from a fumarole on Mt. Pelée, Martinique, found a similar percentage, 1.28. In two samples of gas from fumaroles in Guadeloupe, however, the same chemist obtained higher results, *viz.*, 1.98 and 2.96. Porlezza and Norzi [6] obtained 1.78 per cent. in the soffioni of Larderello, Italy.

E. S. Shepherd [7] has examined many samples of volcanic gases from Kilauea and two from Mauna Loa. In most of the samples the ratio of argon to the total inert constituents is much higher than it is in the atmosphere, and generally indeed above 3 per cent., but a few samples contain no argon at all. Strangely enough, the argon does not vary all the way between the limits; only one value occurs between zero and 1.96. These results are obviously at variance with Moureu's hypothesis.

The gases collected from the crater of Kilauea in 1912 by Day and Shepherd [8] probably came nearer representing true mag-

[3] Moureu and Biquard, *Compt. rend.*, **143**, 180, 1906. Moureu and Lepape, *Compt. rend.*, **149**, 1171, 1909; **152**, 934, 1911; **153**, 740, 847, 1043, 1911; **155**, 197, 1912; **171**, 941, 1920.

[4] *Compt. rend.*, **148**, 1708, 1909; **149**, 84, 1909.

[5] *Compt. rend.*, **135**, 1085, 1902; **138**, 936, 1904.

[6] *Atti Acad. Lincei*, **20**, ii, 338, 1911.

[7] *Bull. Hawaiian Volcano Obs.* vii, No. 7, July, 1919; viii, No. 5, 1920.

[8] *Bull. Geol. Soc. Amer.*, **24**, 573, 1913.

matic gases than any other samples that have been collected. Yet if we accept the conclusions of Jaggar,[9] respecting the lava lake of Kilauea, air is being continually carried down by convection from the surface to the deeper layers of the magma; the oxygen is entrapped in viscous but vesicular lava blocks at the surface, probably combines rapidly with the ferrous iron of the lava and is consumed at lower levels in the oxidation of portions of the magmatic gases. Consequently some of the nitrogen and its congeners may come from the atmosphere. Respecting the relation of argon to nitrogen one might therefore conclude, either that the gases of Kilauea are all magmatic and variable in composition or that the inert constituents of some samples are wholly or partly of atmospheric origin and that some nitrogen as well as oxygen has been absorbed by the lava. In any case the magmatic gases must be highly variable.

This line of work deserves to be pursued further with the purpose of finding whether the relations of the inert gases can be regarded as a criterion for the magmatic origin of these constituents in volcanic gases. The data on this point so far as they could be found are tabulated in Table 1.

(2) *By Addition of Volatile Products from Outside Sources.*—So far as known, rocks of all kinds give off some gas when they are heated. Rocks which are subjected to volcanic intrusion may therefore be expected to give off gases. The gas which will be driven off in the largest quantities is steam, for nearly all rocks contain water, and it requires only a moderate temperature to drive out the greater part of it. The carbonates of calcium, magnesium and iron are easily dissociated, giving carbon dioxide; and the sulphides in general either by thermal dissociation or by well-known reactions with water or air give, at no very high temperatures, sulphur, hydrogen sulphide or sulphur dioxide, according to prevailing conditions. Bituminous shales and similar materials when heated are certain to give the products of dry distillation—hydrocarbons, especially marsh gas, carbon dioxide, ammonia and tarry matter. While such reactions are sure to be induced under certain conditions, carbon dioxide, marsh gas and ammonia are common volcanic emanations occurring in many places where there is no positive evidence of the presence of limestones, sulphide deposits or organic materials. From general con-

[9] *Bull. Seismolog. Soc. Amer.*, x, 155, 1920.

TABLE I.

Relation af argon to the total inert constituents of volcanic gases.

No.	Locality	% N_2	% A	$\frac{A}{A+N_2}\times 100$
1	Mt. Pelée, Martinique	54.94	.71	1.27
2	Guadeloupe, W. I.	36.07	.73	1.98
3	Guadeloupe, W. I.	22.32	.68	2.96
4	Larderello, Italy	1.35	.0245	1.78
5	Vesuvius	17.62	.243	1.36
6	Lago d'Agnano, near Naples	2.87	.028	.99
7	Kilauea, T. H.	12.88	.45	3.38
8	Kilauea, T. H.	3.50	.07	1.96
9	Kilauea, T. H.	5.88	.18	2.97
10	Kilauea, T. H.	.87	.14	13.87
11	Kilauea, T. H.	8.92	.29	3.15
12	Kilauea, T. H.	2.44	.39	13.78
13	Kilauea, T. H.	2.37	.56	19.11
14	Kilauea, T. H.	2.33	.00	.00
15	Kilauea, T. H.	20.01	.00	.00
16	Kilauea, T. H.	2.41	.14	5.4
17	Kilauea, T. H.	15.03	.21	1.3
18	Kilauea, T. H.	4.13	.31	6.9
19	Kilauea, T. H.	.68	.05	6.8
20	Kilauea, T. H.	3.35	.66	13.9
21	Kilauea, T. H.	2.91	.00	.00
22	Kilauea, T. H.	6.20	.16	2.5
23	Kilauea, T. H.	3.11	.08	2.5
24	Kilauea, T. H.	1.29	.04	3.0
25	Kilauea, T. H.	4.50	.12	2.6
26	Mauna Loa, T. H.	16.80	.58	3.34
27	Mauna Loa, T. H.	15.39	.42	2.66
		cc N_2	cc A	$\frac{A}{A+N_2}\times 100$
28	Katmai Region, Alaska	23.91	.31	1.28
29	Katmai Region, Alaska	26.34	.29	1.09
30	Katmai Region, Alaska	7.42	.09	1.20
31	Katmai Region, Alaska	26.65	.42	1.55
32	Katmai Region, Alaska	4.45	.05	1.11
33	Katmai Region, Alaska	175.90	1.984	1.11
34	Katmai Region, Alaska	20.36	.26	1.26
35	Katmai Region, Alaska	8.31	.10	1.15
36	Katmai Region, Alaska	21.25	.32	1.48

Nos. 1, 2, and 3 made by Moissan, *Comp. rend.*, **135**, 1085 (1902); **138**, 936 (1904).

No. 4, made by Porlezzi and Norzi, *Atti. Acad. Lincei*, **20**, II, 338 (1911).

Nos. 5 and 6, made by Gautier, *Comp. rend.*, **148**, 1708 (1909) (argon in 5 by Moureu); **149**, 84 (1909).

Nos. 7–27, made by Shepherd, *Bull. Hawaiian Vol. Obs.*, **7**, 94 (1919); **8**, 65 (1920); **9**, 86 (1921).

Nos. 28–36, made by Allen and Zies, unpublished.

TABLE I.—*Continued.*

No.	Locality	% N_2	% A	$\frac{A}{A+N_2} \times 100$
37	Iceland Reykir No. 1	98.49	1.48	1.48
38	Iceland Reykir No. 2	98.36	1.60	1.60
39	Iceland Reykir No. 5	98.34	1.61	1.61
40	Iceland Hveravellir No. 2	16.50	.294	1.75
41	Iceland Hveravellir No. 25	20.6	.441	2.10
42	Iceland Grafarbakki No. 1	90.0	1.68	1.83
43	Iceland Grafarbakki No. 2	93.4	2.15	2.25
44	Iceland Laugaros No. 1	97.4	1.93	1.94
45	Iceland Laugaros No. 3	97.4	2.10	2.11
46	Iceland Reykjafoss No. 1	67.9	1.36	1.96
47	Iceland Hengill No. 1	1.8	.0113	.62
48	Iceland Hengill No. 3	3.9	.088	2.21

Nos. 37–48 made by Thorkelsson, *Mem. Acad. Royal de Danemark*, 8, 182 (1910).

siderations it seems more than likely that emanations of this sort are generated in the early stages of an eruption if at all and that they should, at any rate, decline during long periods of eruptive activity. (T. C. Chamberlain.)

(3) *By Fixation and Removal of Original Acid Gases Through Chemical Reaction.*—In the study of the gases from the Katmai fumaroles [10] we found that hydrochloric acid and hydrofluoric acids were of general occurrence and that their concentrations were comparable to those of carbon dioxide and nitrogen, respectively. In vents of low temperature (around 100°) the quantity of the acid gases was always small and this agreed with qualitative tests in the field. It was also a conspicuous fact that the saline incrustations caused by the acid gases were almost entirely wanting about vents of low temperature. Unfortunately the samples of gas from the hotter fumaroles were not collected under conditions which made it possible to establish any *quantitative* relation between temperature and acid concentration, but the results as they stand show that the concentration of acid is low when the temperature is low.

Our explanation of this phenomenon is quite a simple one. The Katmai fumaroles are usually lined with a coating of oxide of iron, probably for the most part derived from the minerals of the pumice from which the gases issue, but perhaps to some extent by an indirect process from deep-seated emanations. Ferric oxide reacts with the halogen acids, giving the corresponding salts and

[10] Allen and Zies, *loc. cit.*

water. $Fe_2O_3 + 6HCl \rightleftarrows 2FeCl_3 + 3H_2O$ and $Fe_2O_3 + 6HF \rightleftarrows 2FeF_3 + 3H_2O$. Both these reactions proceed from right to left with absorption of heat,[11] consequently the higher the temperature, other conditions remaining the same, the greater should be the proportion of acid in the gases. Supposing then that a mixture of halide and oxide of iron in the walls of the fumaroles was swept by an equilibrium mixture of steam and hydrochloric acid gas, there would be neither gain nor loss in the concentration of acid in the gaseous phase and the concentration would be fixed by the temperature. There is no certainty that the rushing gases actually adjust themselves to an equilibrium with the solids, and furthermore the percentage of water vapor is so very great in all the Katmai gases that it may surpass the equilibrium pressure at the *highest* temperatures so that none of the acid is fixed, but at *lower* temperatures the present imperfect data permit the hypothesis that the equilibrium pressure of acid is there so low that more and more acid is fixed with falling temperature. As stated above, the Katmai fumaroles of low temperature are exhaling comparatively little acid and forming as a rule no saline incrustations about the vents. Those vents which are lined with oxide of iron were probably once hotter than now, while those which contain none probably were never very hot; most of the gases, presumably, having been fixed by reactions taking place below the limit of our vision. The acids may not confine their attack exclusively to oxide of iron; other oxides, more especially alumina, have been, and perhaps still are being, liberated from the minerals in the walls of the fumaroles by the combined action of the steam and acids just as the oxide of iron has been liberated. Whether the hypothesis is correct or not, we find in the Katmai fumaroles a connection, though imperfectly worked out, between the temperature of the vents and the concentration of the strong acid gases which issue from them. Though we have not the data to show it, the readiness with which hydrogen sulphide reacts with ferric oxide makes it practically certain that some of this gas is also removed and fixed by chemical reactions of this kind, and the same statement holds good for sulphur dioxide where that is an original gas.

(4) *By Addition of Water of Surface Origin.*—We have seen that water in surface rocks may be driven out by the heat of a volcanic intrusion. The same is true of ground water. Consider-

[11] According to Le Chatelier's principle.

able water is probably always expelled by a lava stream from the ground beneath it, and the steam thus formed may be mingled with the gaseous emanations from the lava.

Lacroix [12] has given excellent evidence for the existence at Martinique of secondary fumaroles or "fumaroles without root" which he regards as the result of surface water acting on hot volcanic detritus. The water is vaporized by the heat, and the steam reacts chemically with the detritus forming small amounts of the volcanic gases.

On the other hand, many of the fumaroles of the Katmai region [13] are so long-lived, so hot and so definitely related to surface fissures that we have regarded them as primary in the sense that some of the gases at least are thought to be rising directly from hot lava. Yet even here there is strong evidence of the dilution of the original gases by steam from surface sources. In all these fumaroles, so far as examination goes, water is the preponderating constituent, ranging from about 98.5 to 99.85 [14] per cent. by volume. The water was determined by condensing and measuring the quantity of it which accompanied a measured amount of fixed gas. When we express this quantity as the ratio between the volumes of *liquid* water and fixed gas, it is found that the ratio varies from 0.06 to about 15.0. That is, the volume of the water compared to a unit volume of fixed gas varies within wide limits, as it should if surface water, in amounts naturally variable, finds access to the original gases. The smallest quantity of water occurred in samples which were collected close to the only area where extruded lava actually reaches the surface, and where the gases might have been expected to be least affected by surface influences. It was also found that, as a rule, the largest quantity of water occurred in fumaroles which, from the topography, seemed most likely to have been affected by surface water.

A calculation of the amount of water flowing at a given time into the drainage basin in which these fumaroles occurred, and a comparison with that flowing out of it at the same time, proved that the inflow was in large excess. The observations also indicated that this excess must be evaporated chiefly about the fuma-

[12] "Montagne Pelée et ses Eruptions," Paris, 1904, p. 390.

[13] Allen and Zies, unpublished.

[14] Allowance is here made for hydrochloric and hydrofluoric acids which are not included in the *corresponding* analyses at the end of this paper.

roles, and our hypothesis assumes that the steam was drawn through the fumarole walls as others have supposed the atmospheric gases are drawn in. If our findings are correct, the water in the Katmai gases is largely of surface origin, yet even where the gases have presumably been least exposed to surface influences, water is still the preponderating constituent.

The dilution of fumarole gases by steam from surface water has probably always been believed by many geologists, but the evidence for it, so far as we are able to find, is seldom so convincing as it is here.[15]

(a) *The Insignificance of Surface Water in Carrying Down Dissolved Nitrogen.*—Bunsen [16] states that the nitrogen of the Icelandic fumaroles is of atmospheric origin and is carried down in solution by surface water. It is a minor matter, still perhaps worthy of notice, that only a very small fraction of the nitrogen could have been carried down in that way, for a saturated solution of nitrogen in water at 15° and the partial pressure of nitrogen in the air would, if volatilized without change in composition, have formed a gas containing only about 0.001 per cent. of nitrogen by volume, whereas the only sufficiently complete analysis of an Icelandic gas, quoted by Bunsen, contained 0.3 per cent. nitrogen and 82.3 per cent. water.[17] The same is true of all recorded analyses of volcanic gases where water and nitrogen are both determined, including the analyses of the Katmai gases; if the water were *all* surface water there would in no case be nearly enough of it to dissolve all the nitrogen. (See Table 2.)

II. The original volcanic gases.

(1) *Summary of Analytic Evidence.*—In the foregoing critique it has been maintained that oxygen in volcanic gases is invariably exotic and that it comes from the air. This implies that at least an equivalent quantity of the inert gases, nitrogen, argon, etc., must have accompanied the oxygen. Evidence has been given which indicates that in some cases the inert gases are wholly or chiefly from atmospheric sources, while in others they

[15] See also Brun's statement to the effect that fumarole gases show seasonal variation. "Recherches sur l'Exhalaison Volcanique," Genève, 1911.

[16] Liebig's Ann., **62**, 8, 1847.

[17] Gas from a fumarole at Krisuvik, *Ann. Chim. Phys.*, (3) **38**, 264, 1853.

TABLE II.

Analyses of volcanic gases which include both H_2O and N_2.

Locality	Per cent. H_2O	Per cent. N_2	Authority
Krisuvik, Iceland	82.3	0.3	Bunsen[1]
Vesuvius	67.74	15.49	Gautier[2]
	62.44	24.88	
	72.69	21.23	
	77.76	17.62	
Kilauea	67.99	23.22	Shepherd[3]
	38.48	37.84	
	17.97	12.88	
	64.71	10.47	
	89.77	3.50	
	64.18	5.88	
	75.08	0.87	
	59.97	8.92	
	89.93	2.44	
	75.09	7.92	
	80.31	2.37	
	84.98	2.33	
	78.71	20.01	
	36.18	2.41	
	50.88	15.03	
	61.56	4.13	
	97.09	0.68	
	67.52	3.35	
	76.84	2.91	
	73.89	6.20	
	66.25	3.11	
	79.31	1.29	
	61.88	4.50	
Mauna Loa	75.44	16.80	Shepherd[4]
	67.43	15.37	
Katmai, Alaska	99.97	0.017	Allen and Zies[5]
	99.99	.003	
	99.93	.018	
	99.96	.015	
	99.96	.018	
	99.95	.024	
	99.90	.024	
	99.94	.009	
	99.40	.049	
	98.60	.179	
	99.95	.006	
	99.94	.002	
	99.96	.004	
	99.70	.268	
	99.96	.004	

[1] *Ann. chim. phys.*, (3) **38**, 259. 1853.
[2] *Compt. rend.*, **148**, 1708. 1909.
[3] *Bull. Hawaiian Vol. Obs.*, **7**, 94-97, July, 1919; **9**, 86, 1921.
[4] *Bull. Hawaiian Vol. Obs.*, 8, 65-67, May, 1920.
[5] Unpublished.

are either of deep-seated origin or they possibly have been changed by selective solubility [18] in the magma.

Carbon dioxide, ammonia, and the sulphur gases, while they may find occasional access to the conduits of volcanic gases from outside sources, are of too general occurrence for us to connect them invariably with comparatively superficial formations, for the local existence of which there is often not the slightest evidence.

A satisfactory superficial source for hydrochloric and hydrofluoric acids has, I believe, never been pointed out. Some indeed would derive the chlorine in volcanic gases from sea-water, because volcanoes so frequently occur near the sea-coast; but the gases of the volcanoes of Iceland and Hawaii are singularly low in it, while the gases of the inland volcanoes of Mexico contain it. Furthermore, there is too little fluorine in sea-water to supply, without great concentration, the amounts found in the Katmai gases. While both hydrochloric and hydrofluoric acid gases are doubtless original, we have seen that their quantities are subject to reduction by chemical reactions with the minerals which constitute the walls of the fumaroles.

In addition to the changes which have been described, fumarole gases emerge from the ground at temperatures probably considerably below that of the magma, whence they come, and are therefore subject to chemical changes resulting from shifts in equilibrium. A similar shift of equilibrium may be expected in the process of collecting the gases, especially where they are very hot unless the chilling is very rapid. Changes of this character, while they may alter the original amounts of the gases considerably, will not affect our conclusions as to their original character unless some constituent is thereby reduced to a negligible quantity.

(2) *Gases in Igneous Rocks.* (a) *Their Nature and Amount.* —The researches of Gautier,[19] Chamberlin,[20] and others have

[18] The word is used in a general sense; it is not intended to imply a purely physical process. If nitrogen is absorbed by the magma it is probably through chemical combination.

[19] Gautier, *Compt. rend.*, 132, 61, 189, and 932; 136, 16 (1903).

[20] R. T. Chamberlin, "The Gases in Rocks," Carnegie Inst. of Washington, Publ. No. 106. For a complete resumé of the subject see Clarke, F. W., "Data of Geochemistry," 4th ed., p. 268 (1920). See also Brun, A., "Recherches sur l'Exhalaison Volcanique," Genève, 1911.

shown that all igneous rocks contain gases which they give up when heated in a vacuum. The principal constituents of these gases are water, carbon dioxide and hydrogen, while carbon monoxide, nitrogen, methane and hydrogen sulphide are subsidiary. Ammonia and the halogens, as well as oxygen, are almost entirely wanting.[21]

TABLE III.

Average volumes of various gases obtained from the igneous rocks per volume of rock; reduced to 0° and 1 atmosphere and also to 100° and 1 atmosphere. *

Order	Type of Rock	No. of analyses	H_2S	CO_2	CO	CH_4	H_2	N_2	Total at 0°	Total at 100°
1	Basic schists	2	0.00	4.06	0.19	0.05	3.44	0.13	7.87	10.75
2	Diabases and basalts	14	.19	3.96	.44	.12	2.54	.11	7.36	10.06
3	Gabbros and diorites	11	.02	2.31	.13	.07	2.09	.11	4.73	6.46
4	Granites and gneisses	19	.00	1.47	.22	.05	1.36	.09	3.19	4.36
5	Andesites	7	.00	1.86	.18	.06	.20	.09	2.39	3.27
6	Syenites	4	.00	.18	.07	.05	.91	.04	1.25	1.71
7	Rhyolites	4	.00	.69	.05	.02	.06	.05	.87	1.19
8	Miscellaneous porphyries	2	.00	.32	.06	.04	.33	.04	.79	1.08

* R. T. Chamberlain: "Gases in Rocks," p. 27, Table 13.

TABLE IV.

Average composition of the gases in igneous rocks. Calculated from Table 3 into volume percentages.

Order	Type of Rock	No. of analyses	H_2S	CO_2	CO	CH_4	H_2	N_2	Total
1	Basic schists	2	0.0	51.6	2.4	0.6	43.7	1.7	100%
2	Diabases and basalts	14	2.6	53.8	6.0	1.6	34.5	1.5	100%
3	Gabbros and diorites	11	0.4	48.8	2.7	1.5	44.2	2.4	100%
4	Granites and gneisses	19	0.0	46.0	6.9	1.6	42.6	2.9	100%
5	Andesites	7	0.0	77.8	7.5	2.5	8.4	3.8	100%
6	Syenites	4	0.0	14.4	5.6	4.0	72.8	3.2	100%
7	Rhyolites	4	0.0	79.3	5.7	2.3	6.9	5.8	100%
8	Miscellaneous porphyries	2	0.0	40.5	7.6	5.1	41.8	5.0	100%

The analyses of volcanic gases agree with these results in large measure but not entirely. Nitrogen is generally more abundant in the volcanic gases than in the rocks, a fact which is explained by the atmospheric contamination of the former. The presence of oxygen in the volcanic gases is, as we have seen, similarly accounted for. Hydrogen averages much higher in the rocks—a fact which will be considered later. (See Tables 3 and 4.)

[21] Brun claims to find free chlorine, hydrochloric acid and ammonium chloride in comparatively large quantities in some of these gases, *loc. cit.*

Of the water in the igneous rocks Chamberlain makes very little. He apparently doubts its significance and does not include it in his gas analyses. Gautier is impressed with its importance in volcanology, whatever its origin, and he gives the average quantities of water found by him in several classes of rocks. We will not cite his figures here because the rocks taken for his water determinations were obviously not selected in such a way as to serve our present purpose, which is to determine what relation the water holds to the rocks and to the magmas from which the rocks were formed.

Table 5 contains the average percentages of water "above 100°" in the principal types of igneous rocks as computed by

TABLE V.

Average percentage of H_2O+ in igneous rocks.

	Type of Rock	Washington[1] Number of analyses	Washington[1] Per cent. H_2O	Daly[2] Number of analyses	Daly[2] Per cent. H_2O	Daly[2] Per cent. SiO_2
1	Granite	381	0.64	236	0.78	69.73
	Rhyolite	181	1.54	64	1.52	72.60
2	Syenite	105	0.70	50	0.76	61.99
	Trachyte	97	1.01	48	1.26	60.68
3	Nephelite syenite	72	1.38	43	1.35	54.63
	Phonolite	76	1.71	25	2.04	57.45
4	Diorite	165	0.99	89	1.37	58.38
	Andesite	192	1.17	87	1.26	59.59
5	Gabbro	150	1.01	41	1.45	48.24
	Basalt	198	1.66	161	1.76	48.78

[1] H. S. Washington, data from Prof. Paper 99; U. S. Geol. Survey.
[2] R. A. Daly, from *Proc. Am. Acad. Arts. Sci.*, XLV, 211, 1910.

Washington and by Daly. The classification into five groups is seen to follow composition, from the most to the least siliceous. Each group is subdivided into plutonic rocks (first given) and effusives. In the main the results of the two authors are in satisfactory agreement. The results of Doctor Washington, which he kindly computed for the writer from his well-known "Analyses of Igneous Rocks,"[22] have several claims to first consideration, for: (1) They represent determinations on *rocks entirely free from alteration*, and (2) each average was made from a large number of individual determinations. (3) The rocks to which the water determinations appertain were so selected that plutonic and effusive rocks of the same group are closely comparable in composition. This fact will be later applied to another subject.

[22] Prof. Paper, *U. S. Geol. Survey* No. 99.

If we take 2.65 as the average specific gravity of the granites and 3.00 as the average specific gravity of the basalts, we calculate that the water in the average granite, if entirely expelled at 100° and one atmosphere pressure would occupy a volume thirty times that of the rock, while the water in the average basalt under similar conditions would amount to eighty-seven times the volume of the rock from which it was expelled. A reference to Table 3 shows that these figures far surpass the average volume of all other gases in igneous rocks put together.

The general occurrence of water in the igneous rocks and its high average quantity compared to the other volatile constituents is an indisputable fact, but its significance is not universally accepted.

(b) *The State in Which the Gases are Held in the Rocks.*—Microscopic investigations show that very little of the gases (including water) in rocks can be contained in cavities. Some is probably held in minute cracks which form the boundary planes between the constituent minerals, but the major part is evidently distributed through the minerals themselves and, unless we are content to speculate in the hazy realm of the submicroscopic, the logical conclusion is that they are held by molecular forces. Reverting especially to the water, we know that there are primary minerals, particularly the micas in which all would probably agree that the water is chemically combined. In other minerals where the water bears no simple stoichiometrical relation to the chemical formula there has been a tendency to ignore it, though some include it in more complicated formulæ. This can be done in the case of water with some show of reason, but no one has ever attempted to make hydrogen [23] or carbon dioxide a part of the formula, except in some special case like cancrinite. Whatever may be the exact molecular relationship of water and other gases to the rock, it is a simple conception in good accord with known facts to suppose that a complex solution like a rock magma should, in the act of crystallizing, retain in its constituent minerals some portion of its volatile as well as its non-volatile components, the quantity in each mineral varying according to the composition of the magma, the chemical nature of the mineral and the temperature and pressure to which it is subjected.

(c) *Is Water or Hydrogen the Original Gas?*—Travers and

[23] This of course means hydrogen other than the hydrogen belonging to water.

Gautier have regarded the gases expelled by heat from rocks as not all present originally, but as products of chemical reaction between water and certain minerals in the rock. It is an interesting problem in itself to determine the molecular state of the various gases in the rock, but this will not affect our conclusions regarding the origin of the volcanic gases; we must simply recognize that the relative quantities of certain gases will depend on the temperature at which they are expelled from the rock and upon the extent to which equilibrium between the rock and the gas is attained. For example, Gautier regarded the hydrogen expelled from rocks as a reaction product between water and the ferrous compounds present. We may assume for the sake of simplicity that the reaction is represented by the following equation: $3FeO + H_2O \quad Fe_3O_4 + H_2$, though the ferrous oxide, as a matter of fact, is always *combined,* generally in some more or less complex silicate. However this may be, the reaction between ferrous iron and water in a rock is apparently a reversible one; and if so, any rock which contains these components, as most rocks do, will give off a mixture of hydrogen and water when it is heated and the quantities will depend, as first stated, on whether equilibrium is reached and upon the temperature at which the gases are expelled. The same thing is true of a *magma,* and if we assume either water or hydrogen to have been originally present in the ferriferous igneous rocks, solid or liquid, *the other must be original in the same sense.*

(d) *Which is the Preponderant Gas, Water or Hydrogen?*—In any rock which contains ferrous and ferric iron, in sufficient amount as compared to the water, so that both remain present when the rock is heated, we can not, strictly speaking, define the percentage of water unless we refer to some definite temperature; and an exact determination of the water can only be made by keeping the expelled gases in contact with the rock powder at the constant temperature specified until equilibrium is reached, before the gases are removed and analyzed. No investigator has followed such conditions.

How far, then, can we make any statement regarding the relative amounts of water and hydrogen in a particular rock or in the magma whence the rock originated, defining *amount* in terms of the volume which the two substances would occupy in the gaseous state? We have already seen that the "volume" of water

actually found in rocks is, on the average, in great excess over hydrogen. Now although the determinations are admittedly inexact, it is safe to say that water is in fact predominant as a rule, if not in all rocks, at all temperatures below melting. If the determinations were not approximately correct it would be impossible in the analysis of many rocks to get an acceptable summation, for the disparity in weight between water and its equivalent of hydrogen is very large and the determination of ferrous iron is quite independent of the water determination so that there could be no compensation between the two. Where low percentages of water are found the error might not be detected, but in rocks found to be high in both water and ferrous iron it would be impossible to mistake a preponderant volume of water for a preponderant volume of hydrogen.

Again, the *water content is often considerable in rocks and minerals which are almost free from iron.* Washington lists a pitchstone [24] from New South Wales containing 10.5 per cent. of water by weight and only 0.21 per cent. of ferrous oxide. Assuming 2.25 as the specific gravity of the rock, the water as vapor at 100° and one atmosphere pressure would amount to over 400 volumes per volume of rock. While the hydrogen was not determined, it is safe to say its volume must have been insignificant in comparison, for the hydrogen equivalent to the full amount of ferrous oxide would be very small, and, moreover, Chamberlin's analyses include no igneous rock of any description which contains more than a few per cent. of the above volume. The preponderant water in this rock must therefore have been originally present as such, or at least in a form which would give up water on heating. In the case of this rock, we may safely go farther. Since hygroscopic water (included in the 10.5 per cent.) in rocks of this character is insignificant, and since the rock showed no sign of alteration, we may infer that most of this water was contained in the original magma. This case is selected as an example; no doubt many rocks low in iron and high in water could be found which would confirm the above evidence.

We conclude, then, that while the water determinations in ferriferous minerals and rocks are *not exact,* they are in general

[24] Prof. Paper, *U. S. Geol. Survey,* No. 99, p. 103.

close enough to warrant the statement that the volume [25] of water (as vapor) in the rocks is preponderant over hydrogen.

Does the same conclusion hold good for the magma? Analyses of the volcanic gases show that in the great majority of cases water is greatly preponderant over hydrogen, but it is possible that the gases may have undergone some change after leaving the magma. Jaggar believes that hydrogen is much greater in amount in the *original* volcanic gases than it is in gases which have so far been collected. It is his view that the original hydrogen has suffered partial oxidation on approaching the surface. At Kilauea there is good evidence for surface oxidation, but before accepting Jaggar's view respecting the preponderance of original hydrogen it ought to be noted first that he has no evidence bearing on the *amount* of oxidation. Shepherd [26] makes the following statement on this point, based on the study of the Kilauea gases: "The quantity of water found (in the gases) is much too great to be accounted for on the direct air oxidation hypothesis and the main question answered in 1912—that is as to the supposed 'anhydricity' of the gases has been entirely settled. At Kilauea the major constituent of the gas is water and the question as to its meteoric or plutonic origin has now been fairly well established in favor of the plutonic."

As to volcanic gases in general, it has not been shown that the conditions at Kilauea are characteristic of other volcanic craters. The saucer-like basin in which the lava is peculiarly exposed to the air at all times when gases can be collected and the downward transport of air by floating crust and infalling talus are, so far as known, unique.

When gases arise from lava which stands at a level well below the surface of the ground, and issue in large volumes from narrow funnels, oxidation like that at Kilauea ought to be practically obviated. In volcanoes of this character satisfactory evidence as to oxidation of the gases can only be obtained from such as issue from fumaroles. Although it has been so far impossible to determine how much of the water in such gases is original, some of them contain in the fixed portion more combustible gas than the Kilauea gases do in spite of the fact that fumarole gases as a rule have

[25] It will be understood here that the comparison of volumes presupposes expulsion of the gases from the rock.

[26] *Bull. Hawaiian Volcano Obs.*, 9, 86, 1921.

probably suffered some oxidation. This is generally true of the Katmai gases.

So, while surface oxidation of original volcanic gases may be important in some places, and while various degrees of oxidation probably occur in fumaroles, Jaggar's evidence even at Kilauea itself is by no means sufficient to prove that hydrogen is more important than water in the original volcanic gases. Besides oxidation, however, volcanic gases may undergo other changes after leaving the magma. The simplest is dilution by air or by water vapor. We have shown the probability of this change already. In particular cases this influence might disguise the original character of the gases, but at Katmai, where the gases were collected with particular pains to exclude air, the evidence indicated that the original gases were highly aqueous.

Still another change which volcanic gases may undergo after leaving the magma, already alluded to in a general way, is a shift in equilibrium which obviously has a bearing on the question in hand. The total number of constituents of importance in a volcanic gas is fortunately small, and we can predict with some confidence the principal reactions which apply here. They are:

(1) $CO_2 + H_2 \rightleftarrows H_2O + CO$.
(2) $3S_2 + 4H_2O \rightleftarrows 4H_2S + 2SO_2$.
(3) $H_2S + 2H_2O \rightleftarrows 3H_2 + SO_2$.
(4) $2H_2S \rightleftarrows 2H_2 + S_2$.

In the first reaction—the water gas reaction—a rise in temperature results in an increase in the water; in (2) and (3) the same change results in a decrease in water, while in (3) and (4) the concentration of hydrogen increases.[27]

It would be difficult to calculate what the final result would be in a case of such complexity even if we had the data; the change in the concentration of water and hydrogen with rising temperature would depend on the quantities of the water, the carbon dioxide, and the sulphur gases; but it will be noted that any change in these concentrations which could alter our conclusion regarding the preponderance of water would have to be brought about by the sulphur gases, and we shall find later evidence which indicates that these are usually minor constituents of the magma. This conclusion depends on the assumption that water is preponderant at low temperatures, as it generally is in the rocks,

[27] For the heat effects which govern these reactions see p. 32.

and on the assumption that carbon monoxide is insignificant in comparison.[28]

Some speculation which is pertinent to this question has been done by Daly and by Chamberlin[29] on the reaction represented by the equation

$$3FeO + H_2O \rightleftarrows H_2 + Fe_3O_4.$$
$$192900 \text{ cal} + 59880 \text{ cal} = 264900 \text{ cal} - 12120 \text{ cal}^{30}.$$

It has been noted that in accordance with the heat absorption this reaction should proceed from right to left as the temperature rises; consequently the concentration of water vapor in the gases should increase. The same reasoning has been applied to the reaction which takes place between the water and the ferrous minerals in a rock powder, but our knowledge of these reactions is quite imperfect. The original ferrous silicates—olivine, hypersthene, hornblende, diallage—are easily identified and the evidence of Gautier and Chamberlin indicates a reversible reaction involving either these silicates directly or possibly ferrous oxide forming from them in a preliminary reaction. Gautier states that the action of water on the ferrous silicates produces magnetite or ferric silicate.

As a matter of fact we do not know the products and we are not quite sure that the reaction is reversible. Recently Ferguson,[31] in a series of experiments performed in this Laboratory, was unable to find that steam has any action on the lava from Kilauea, which is quite rich in ferrous silicate, even at 1100°.

If the reaction is really reversible and the *sign of the heat change* is the same in the rock powder and in the magma as it is in the simpler process which we have discussed, the magmatic gases should be richer in water vapor than the gases which are expelled by heat from rocks, and we have already seen that in the latter the volume of water vapor exceeds on the average the volume of all the other gases combined.

Gautier[32] holds interesting views on the relations of water and hydrogen in the magma, but they are not altogether clear.

[28] Like all other constituents in volcanic gases CO is variable, but usually its concentration is low and probably always low compared to water.

[29] R. A. Daly, *op. cit.*, p. 86; R. T. Chamberlin, *op. cit.*, p. 41.

[30] The heats of formation from the elements.

[31] *Jour. Wash. Acad. Sci.*, 9, 539, 1920.

[32] *Ann. des Mines* (10), 9, 344, 368, 1906.

While he believes that water is present in the magma, he apparently regards it as a reduction product of the magmatic oxides by hydrogen which is continuously emanating from the depths of the globe. Hydrogen in the magma as well as in the rocks is (he believes) also liberated by the reaction of water with ferrous minerals. If he accepts the reversibility of the reactions, his statements imply that the ratio of water vapor to hydrogen *decreases* as the temperature rises. This view may be legitimate in view of the conflicting evidence, but a *discontinuous* change from water in the magma to hydrogen in the depths of the globe is out of accord with chemical principle.[33]

(e) *Other Chemical Reactions Between Water and Minerals.*—Water reacts with the sulphides and halides (if present) in the rocks, when they are heated, with the formation of hydrogen sulphide (and its decomposition products) and the halogen acids; but very small quantities of hydrogen sulphide are actually obtained from rocks by this process and the halogen acids have not been detected at all in analyses of the gases.[34] Nevertheless these gases are a characteristic part of the emanation from many volcanic craters, and the chemical properties of the gases and of lavas justify us in assuming that the former are products of the reaction of water on sulphide and halide molecules dissolved in the magma. These sulphides and halides are all decomposed by water with absorption of heat, as the following typical equations show:

$3FeS + 4H_2O = Fe_3O_4 + 3H_2S$ (Gautier).

-56400 cal-239520 cal $= 264900$ cal $+ 20100$ cal-10920 cal or

$\frac{10920 \text{ cal}}{4} = -2730$ cal per mol H_2O.

$CaCl_2 + H_2O = CaO + 2HCl$.

-183900 cal-59880 cal $= 145000$ cal $+ 44000$ cal-54780 cal.

$CaF_2 + H_2O = CaO + 2HF$.

-238800 cal-598800 cal $= 145000$ cal $+ 77000$ cal-76680 cal.

As in a previous case, we must be cautious about applying these equations *to the magma* where the heats of solution by the magma of all the different substances enter into the result. But heats of solution are as a rule much lower than heats of formation from

[33] This statement is not to be understood as a denial of the gradual dissociation of water in the magma at *very high* temperatures.

[34] Except by Brun.

the elements.[35] In the case of the second and third equations, at any rate, the heat effect is so large that a change in its sign by solution of all the substances in the magma appears quite improbable. Assuming the correctness of our inferences, there should be more of the halogen acids in the magma and in the vapor phase at *high* temperatures in accordance with the heat absorption and the higher vapor pressure. In other words, the maximum concentration of these gases in the volcanic exhalations should be found when the eruption is at a climax. This may also be true of hydrogen sulphide and its dissociation products, though the case is not so clear as it is for the halogens, for the heat in the reaction as represented is comparatively small and may change in sign when it goes on in the magma.

This reasoning depends on a previous conclusion (pp. 14 and 16) which should be kept constantly in mind, *viz.*, that the volume of water dissolved in the magma is, as a rule, greatly in excess of the volume of all other gases. Water is involved in a number of chemical reactions which doubtless take place in the magma; consequently the mass of it in a unit volume of magma is subject to variation *from several sources,* as the temperature changes. If the mass of water therefore were sufficiently small the conclusion respecting the concentration of halogen acid (and hydrogen sulphide) in the volcanic gases would no longer hold good. These statements apply to the original gases. We have seen that the latter may be further modified when they issue from fumaroles.

The inference respecting the amounts of the halogen acids in volcanic gases is not entirely borne out by field evidence. Deville and others state that the emanations from certain incandescent lavas are chiefly *sodium chloride,* while *hydrogen chloride* is obtained when the eruption has waned somewhat, or in a less active part of the field at the same time. This may possibly mean that certain lavas are low in water, as Deville[36] affirmed, though the evidence *in general* is decidedly against this claim.

(f) *Reactions Between Certain Gases.*—We have so far considered those volcanic gases which result from interaction between water and certain constituents of the rocks though both the water

[35] The heat effect of changing CaO to $CaSiO_3$ and liquefying the same is about 48000 cal compared to 145000 cal (Moissan) for the heat of formation of CaO. The heats of "solution" of $CaCl_2$, HCl and H_2O are probably high, but much lower than their heats of formation.

[36] Deville and Leblanc: *Bull. Soc. Geol.,* France (2), 13, 606, 1855–6.

and the product are to be regarded as original. It should also be noted that the coexistence of certain gases necessarily gives rise to others. Thus carbon monoxide is known to be a reduction product of carbon dioxide by hydrogen. $CO_2 + H_2 \rightleftarrows CO + H_2O$. Further reduction of carbon monoxide by hydrogen with the formation of marsh gas appears to be an accomplished fact, though its formation at *high temperature* as claimed by Gautier is in ill accord with almost complete thermal dissociation at 800° asserted by others.[37]

The oxidation of sulphur vapor by carbon dioxide: $S_2 + 4CO_2 \rightleftarrows 2SO_2 + 4CO$ has been carefully investigated by Ferguson.[38]

Ferguson's results show that below 900° the reduction of carbon dioxide by sulphur vapor is unimportant. They also permit us to calculate, where the composition of the gas is known at any temperature, the shift in equilibrium over any temperature interval.

Another gas reaction which would seem altogether probable in the magma is that between sulphur and water: $3S_2 + 4H_2O \rightleftarrows 4H_2S + 2SO_2$, for though the products of the reaction are incompatible at low temperatures they are not so at high temperatures.

Still another reaction equally probable is: $3H_2 + SO_2 \rightleftarrows 2H_2O + H_2S$.

Since these reactions are all well known, we may see from a glance at the equations that any primary volcanic gas which contains the common constituents water, carbon dioxide and carbon monoxide and at the same time any one of the sulphur gases must contain all the rest. It is, however, certain that SO_2 would often be entirely decomposed by excess of H_2S before it reached the collecting tube. The field conditions brought out in our critique have shown that some oxidation of combustible gases is likely to occur before the collecting point is reached, and since sulphur and sulphur dioxide are both oxidation products of hydrogen sulphide, both may be secondary gases.

All these reactions have necessarily been considered one by one, but it will be evident that they are closely related as parts of the same complex system consisting of the magma alone or embracing the gas phase above it when there is one. In this system of course the molecular forces are all striving toward a chemical equilibrium

[37] See Abegg's "Handbuch der anorg. Chem.," iii, p. 73, Leipzig, 1909.

[38] *Journ. Am. Chem. Soc.*, **40**, 1626, 1918.

—an equilibrium which, however, may never be reached because of opposing forces.

(3) *The Origin of Sulphur, Chlorine and Fluorine in the Volcanic Gases.*—The quantities of sulphur (as H_2S, SO_2 and free sulphur), as well as chlorine and fluorine which occur in volcanic gases, lead us to the magma as their probable source. If they occur there, a residual portion should still exist in the igneous rocks along with hydrogen, carbon dioxide, etc. Investigators in this field have evidently not recovered the halogens and only a very little sulphur by heating rock powder in a vacuum (see p. 12). Perhaps their failure is accounted for by experimental difficulties, as small quantities of these elements occur in igneous rocks. At first sight the amounts seem insignificant, but calculation proves that the *volumes* are comparable with those of the other gases with the exception of water, carbon dioxide and hydrogen. If we accept the average weight pecentages of sulphur, chlorine and fluorine [39] as 0.08 per cent., 0.096 per cent. and 0.04 per cent., respectively, and if we assume that all three are converted by the action of water entirely into H_2S, HCl and HF, the volumes of the gases at 0° and one atmosphere pressure would amount to 1.5, 1.7 and 1.3 volumes per volume of rock. (Compare Table 3.)

When volcanic activity takes the eruptive form a large portion of the sulphur and halogens are lost to the air with other volcanic gases, but a portion is fixed in the walls of the fumaroles or forms incrustations on the ground about the vents. Among the fumarole products at Katmai are found zinc, copper, and molybdenum [40] in amounts which are large compared to those found in the ash on which the incrustations occur. Whether these metals as halides were driven out of the magma along with the more generally recognized volcanic gases is not yet known, but it may well be. Interesting possibilities suggest themselves regarding the extent to which halides like those of the metals in question can be carried along by a gas consisting largely of steam which must tend to hydrolyze the halides and precipitate the oxides of the metals—by a gas containing also sulphur or sulphide of hydrogen which tends to precipitate the metals as sulphides. How great a partial pressure of the halogen acids compared to those of the

[39] Clarke and Washington, unpublished work.

[40] Work on the incrustations of the Katmai fumarolic area is in progress and will be published in a forthcoming paper by E. G. Zies.

steam and hydrogen sulphide would be required to prevent precipitation of these metals from the gaseous state is a problem for the chemist.

When volcanic activity assumes the *intrusive* form geologic investigation reveals very commonly a segregation of the sulphur and fluorine of the magma, together with various metals which form volatile halides, in the form of veins. The whole process is still obscure. To what extent a preliminary volatilization occurs is not known, but there seems to be no obvious relation between the volatility of the halides of the metals and the order of deposition of the metals in the veins. The order suggests crystallization from solutions, which leads to the inference that the final process in filling of the veins was accomplished through the agency of hot waters derived by condensation from magmatic gases but augmented no doubt by ground water.

(4) *The Ultimate Origin of the Volcanic Gases.*—Thus nearly all the volcanic gases are traced directly to the igneous rocks, and the evidence is strong that they formed a part of the magmatic solution from which the rocks crystallized. We shall not attempt to trace them further. Those who adhere to the planetesimal hypothesis may find comfort in the fact that meteorites contain similar gases, and that the meteorites may therefore be the ultimate origin, but it seems equally plausible that these elements form a part of the cosmic material of which all the heavenly bodies are composed.

From numerous eruptive vents the volcanic gases are pouring forth, and have been pouring into our atmosphere since the beginning of time. What becomes of them? Do they disappear in various natural processes like the oxidation of the combustible gases and the absorption of carbon dioxide by plants; are they swallowed up by the vast volume of the air in which their amounts are entirely negligible, or is our atmosphere very slowly changing?

Gautier [41] sees in the eruptive process, especially in the milder form which according to him involves the *distillation* of water and other gases from the rocks, giving rise to the hot springs, one phase of a vast system of circulation, the other of which returns the water and atmospheric gases to the rocks which have lost them. The geological effects of water, oxygen and carbon dioxide in the surface strata of the earth are of course universally recognized,

[41] *Ann. des Mines* (10), 9, 269, 1906.

but "gravity, capillarity and chemical action" do not appear to me competent to return the volcanic gases to their original source. The theory seems chimerical in spite of the attractiveness of its element of natural economy.

III. DEVILLE'S GENERALIZATIONS RESPECTING THE VOLCANIC GASES.

I. Statement and interpretation of the generalizations.

About seventy years ago Deville,[42] as a result of extensive investigations, formulated a number of interesting generalizations which correlated the composition of volcanic gases with the progressive stages of a volcanic eruption. He maintained: (1) That the composition of the volcanic gases passes through a number of distinct stages as one proceeds outward from an eruptive centre. Thus from incandescent lavas the exhalation is principally anhydrous vapor of sodium chloride. In the next stage the gases consist of steam, hydrochloric acid, and sulphur dioxide. In a third stage carbon dioxide is dominant, and finally water vapor alone. (2) That as an eruption dies out, the different stages succeed one another at a given point in the same order. (3) That the same changes follow one another in the same order all over the globe.

Fouqué later corrected Deville's statement regarding the generally anhydrous nature of the gases from incandescent lava, but with more or less modification these generalizations seem to have been commonly accepted by volcanologists. The generalizations imply that the original gases are the same all over the globe and that their subsequent variations are due entirely or chiefly to temperature changes, or that if any other agency has been active it is everywhere equally potent. This is obviously not the same thing as saying that a gas mixture possesses a different equilibrium for every temperature; the gases in certain of Deville's stages contain elements which were not present in the beginning in any form whatever. The generalizations rather suggest that the gaseous mixtures form a part of more complex and variable heterogeneous systems and that their composition is a result not only of reactions among themselves but with other substances,

[42] Deville and Leblanc: *Bull. Soc. Geol.*, France, 2nd Series, 13, p. 606 (1855-6); 14, p. 254 (1856-7). See also F. von Wolff: "Vulcanismus Stuttgart," 1914, p. 563.

notably the constituents of the magma from which they emanated.

II. The actual relations existing between temperature and the composition of volcanic gases.

One of the main objectives in the investigation of the Katmai fumaroles was to find whether there was any relation between the composition of the gases and the temperature at which they issued from the ground. Careful temperature measurements were therefore made in all the vents from which gases were taken. The temperatures varied from 100° to 440°. There was considerable variation in the composition of the gases, but it was impossible to discover any systematic variation in respect to any constituent except the acid gases, hydrochloric and hydrofluoric acids, the concentration of which was obviously dependent on temperature. The marsh gas varied from practically nothing to over 10 per cent. but, so far as our investigation went, the variation was of a purely local character; the gases containing the larger percentages were all confined to a single small basin.

Having satisfied ourselves that the variations in the composition of the Katmai gases were not due chiefly to temperature differences, we made a survey of the whole literature of the subject. It is not surprising to find that temperature data are commonly wanting, but a consideration of the available data showed no such systematic variation as Deville's generalizations imply. Wolff [43] in his book on volcanology comes to a similar conclusion, except that he regards the vapors of sodium chloride as characteristic of incandescent lavas. But even this is not general; in Hawaii [44] and in Iceland scarcely any chlorine has been found in the exhalations. Chlorine seems not to be a component of all magmas and apparently fluorine is insignificant in some. Nor is there any reason to suppose that there should be uniformity respecting the volatile components of a magma while there is certainly none respecting the non-volatile components. When we come to consider the presence of gases *containing the same elements*, H_2, H_2O; CO_2, CO and CH_4; S, H_2S, SO_2, we have seen that the question is not simply one of equilibrium between the gases themselves escaping from an indifferent solvent; the non-volatile portions also enter into the system. Iron in the magma

[43] Vulkanismus. Bd. i, p. 580.

[44] Brun's evidence conflicts with this statement.

directly conditions the relative quantities of H_2O and H_2, and the quantity of iron varies in different lavas even from the same crater.

Equilibrium between the gases and the magma may or may not be attained. Explosive processes are proverbially unfavorable to equilibrium so that eruptions of the explosive type might be expected to cause variations in the gases for this reason alone. Nor do disturbing conditions cease with the release of gases from the magma. If the gases find their way to the surface through fumaroles, they are liable, as we have already found, to lose some of their constituents by reaction with the minerals in the walls of the fumaroles, or to gain others in various ways. In view of all the disturbing influences uniformity could hardly be expected. A certain degree of it may exist in particular localities, but such a degree of regularity as Deville imagined certainly does not exist.

IV. THE MAGMA CHEMICALLY CONSIDERED.

I. The complexity of the process of solution of gases.

We have seen that the solution of many of the gases in a magma must be a highly complex process. The solution of water, for instance, probably results in the formation of many oxide molecules by interactions with ferrous oxide and with sulphides and halides in the melt. At the same time other molecules like hydrogen, hydrogen sulphide and the halogen acids are liberated. Some of the water may also form hydrate molecules, while the displacement of silica by water at high temperatures, according to Arrhenius' hypothesis may also be a possibility. If we regard the solution of hydrogen sulphide or a halogen acid by itself, it is highly probable, as we have seen, that a portion would dissolve with the formation of water and of sulphide or halide molecules. This we may legitimately infer from the minerals which are found in the rocks and from general chemical knowledge.

Molecular forces in the magma are tending to bring the whole mass toward homogeneity and chemical equilibrium, but they may be thwarted by other forces. It might as well be conceded at once that *an actual magma in a state of equilibrium is unthinkable;* the temperature gradient of the globe would prove an insurmountable obstacle to thermal uniformity and consequently to chemical equilibrium. This statement would hold good even if the globe, according to an old theory, were a molten mass beneath

a solid crust; the upper strata would still be cooler than the lower. So much the more would the statement be true if volcanic activity were decidedly localized and the magma were limited by colder material like a mass of hot glass in a pot. This would apply especially to great masses of magma, but it might seem possible that comparatively small masses should show approximate homogeneity. The long series of careful observations that have been made at Kilauea by Green, Jaggar, Day and Shepherd, Daly and others, prove conclusively that the magma there is very far from homogeneity; there are pools or wells of hotter and thinner liquid supported at various levels by a stiff viscous paste—which is circulating by convection in the crater and the gases differ in volume and composition at different points and at different times. In this highly fusible lava stirred by comparatively effective circulation one would suppose, if anywhere in a natural magma, homogeneity might be found. The reality is quite otherwise.

Obviously, then, we must proceed cautiously in the attempt to apply laboratory generalizations to rock magmas. Yet I believe it is possible, using the equilibrium state as a limiting case, to apply certain principles which may help to clear up a little of the confusion which sometimes manifests itself in the literature of the subject.

II. The laws which are supposed to apply to the magma.

In the first place there is no reason to believe that the magma is an exceptional liquid in its behavior respecting the solution of gases; the process should be attended with a positive heat effect as it is with all other liquids, and it should respond to pressure and temperature in the same way.

For example, the solution of a gas in a magma ought to increase with pressure as it does for all similar cases. As a result gas bubbles would be expected to disappear entirely at the enormous pressure in the greath depths of the earth. Failure to recognize this appears to be a fatal defect in Daly's two-phase convection theory when applied, as it is by him, to depths of tens of miles.[45]

This objection has already been noted by others.[46] There is also no known reason why the solubility of gases in a magma

[45] *Proc. Am. Acad. Arts Sci.*, 47, 47, 1911.

[46] Day and Shepherd: *Bull. Geol. Soc. Amer.*, 24, 573, 1913; Jaggar: *Bull. Seis. Soc. Amer.*, 10, 168, 1920.

should not increase with falling temperature so long as the magma remains liquid. There is, however, evidence which indicates that magmas may give up gas abruptly in the process of crystallization. It is a fact of common observation in this Laboratory that silicate melts give out a visible amount of gas when they crystallize. I once saw a melt of this kind froth over at the moment of crystallization, forming a vesicular mass. Other facts of an apparently analogous character are known. Perhaps the most pertinent is the release by molten silver of dissolved oxygen at the moment of freezing. These facts appear to mean that gas may have a much higher solubility in a liquid phase than it does in the solid at the same temperature. The conclusion is confirmed in respect to the solubility of *water vapor* in magmas, by the analyses of rocks.[47]

Reference to Table 5 shows that the several classes of effusive rocks all average higher in water than the plutonic rocks of comparable composition. Now the latter are completely crystalline, while the former are nearly always more or less glassy—some of them completely glassy; that is, in a thermal sense they are still partially or wholly liquid. Of course there is great variation in the amount of water that individual effusive rocks contain. The variation is due no doubt to original differences in different magmas and to the diversity of physical conditions which they have passed through—more especially in their rate of cooling. Nevertheless the basalts in general contain more water the more glassy they are, and the very highest percentages of water occur in the pitchstones which are entirely glassy.

These facts indicate that magmas give up a notable percentage of their water in the act of crystallizing.

It should be admitted in this connection that the pumices which are a characteristic product of explosive activity are chiefly glassy, though it may be possible, as Daly [48] believes, that a crystallization of the cooler portion of the magma next the walls of a sealed crater can result in an evolution of gas sufficient to cause explosion while the great mass of the magma is still liquid.

We have pictured the magma as a two-phase system to assist in explaining what changes may go on in the solution or evolution of gases. How the composition of escaping gases is probably

[47] H. S. Washington: "Analyses of Igneous Rocks," *U. S. Geol. Survey, Prof. Paper* No. 99.

[48] *Proc. Am. Acad. Arts Sci.*, **47**, 47, 1911.

affected by changing temperature has already been touched upon (see p. 20).

Another condition of the magma which interests the chemist is its existence in single phase where pressure entirely prevents the escape of gases. We will consider this condition presently (see V, 2).

V. CHEMICAL ENERGY IN VOLCANIC ACTION.

I. Heat from the decomposition of endothermic substances.

It has been suggested by Arrhenius [49] that the heat of the sun is kept up by decomposition of endothermic substances. While such substances should theoretically be more stable at high temperatures and ought to decompose and give out heat as they cool, the existence of any such substance in magmas is a mere surmise and too little is known of the practicability of the formation of substances of this nature at high temperatures to give the suggestion much standing.

II. Heat from shifting chemical equilibria of the ordinary sort.

It has also been suggested that a great deal of heat may be derived from shifting chemical equilibria [50] of the ordinary sort in a cooling magma. All reactions which proceed with absorption of heat as the temperature is raised must of necessity give out heat when reversed by cooling. Reactions between the volcanic gases and the magma such as we have already considered, and dissociations of gases or of non-volatile substances in the melt so far as they occur, belong in this class. When it is borne in mind that reactions of this character generally involve heat effects of a much higher order of magnitude than specific heats and ordinary heats of solution, the conception seems worthy of consideration. Let us assume now that the reactions we have been considering proceed in the magma without absorption or escape of gas. The following reactions which have already been discussed involve large quantities of heat; at least this is true when each substance is possessed of its characteristic state of aggregation. We have seen that this may be considerably modified (see p. 20) when the substances are all brought into a magmatic solution.

1. $CaCl_2 + H_2O = 2HCl + CaO$—54780 cal.
2. $CaF_2 + H_2O = 2HF + CaO$—76680 cal.
3. $2NaCl + H_2O = 2HCl + Na_2O$—110980 cal.

[49] "Worlds in the Making," p. 91, (New York, 1918).

[50] Daly: "Nature of Volcanic Action," *Proc. Am. Acad. Arts Sci.*, **47**, 47, 1911. Day and Shepherd: *Bull. Geol. Soc. Amer.*, **24**, 573, 1913.

The following reactions involve only moderate heat changes:

4. $3FeO + H_2O = Fe_3O_4 + H_2 + 12120$ cal.

5. $3FeS + 4H_2O = Fe_3O_4 + 3H_2S$—10920 cal (2730 cal per mol H_2O).

The magnitude of the heat effects which result from these reactions will depend first on the *quantity of the substances involved.* Since the percentage of the halogens *in many magmas* at least must be very limited (judging by the gases they exhale and by the residual quantities in rocks) the possible heat effects from any reactions involving them must be correspondingly small. Furthermore the total heat effect from any reversible reaction must of course depend on the *extent of the shift* which the equilibrium undergoes. To take a concrete example, suppose that a magma containing 10 per cent. of water by weight and no other substance which could react with it is cooled from 1880° to about 1200°. Assume further that the water is dissociated over this temperature interval to the same degree in the magma that it is in a state of vapor, and that the mean specific heat of the lava is 0.3 [51] for the whole temperature interval. We can be sure that the heat effect would be almost entirely determined by the heat capacity of the magma. The degree of dissociation of the water at the higher temperature is so small that, in spite of the great heat of reaction, the recombination of hydrogen and oxygen would give a heat effect less than 2 per cent. of the total. Only in cases where the degree of dissociation permits a wide shift in equilibrium can these recombinations assume an important rôle. Only at temperatures much beyond the measured temperatures of magmas does the dissociation of water, for example, or of carbon dioxide become significant.

The degree of dissociation in hydrogen sulphide [52] is indeed large at 1200°, but sulphur is generally, probably always, a minor constituent of the magma. The total heat effect due to recombination is in this case also dependent on a small heat of formation; if Thomsen's [53] formula—$H_2S = 4435 + 1.9t$ cal—holds for high temperatures, it is only about 6700 cal at 1200°.

[51] This value may be too high, but a lava containing so much water would possess an abnormally high specific heat.

[52] Preunner and Schupp: *Zeit. phys. Chem.*, **68**, 161, 1909.

[53] "Thermochemistry," p. 245. Trans. by Burke. (London and New York, 1908.)

A number of gas reactions considered on page 21 involve considerable heat effects. Thus:

$$S_2 + 4CO_2 \rightleftarrows 4CO + 2SO_2.$$
$$387840 \text{ cal} = 116000 \text{ cal} + 138520 \text{ cal} + 133320 \text{ cal}; \text{ or}$$
$$\frac{133320}{4} \text{ cal} = 33330 \text{ cal per mol of } CO_2.$$
$$3S_2 + 4H_2O \rightleftarrows 4H_2S + 2SO_2.$$
$$239520 \text{ cal} = 26800 \text{ cal} + 138520 \text{ cal} + 74200 \text{ cal}; \text{ or}$$
$$\frac{74200}{4} \text{ cal} = 18550 \text{ cal per mol of } H_2O.$$

The following reaction is thermally less important:

$$CO_2 + H_2 \rightleftarrows H_2O + CO.$$
$$96960 \text{ cal} = 59880 \text{ cal} + 29000 \text{ cal} + 8080 \text{ cal}.$$

In making any estimate of the thermal effect of these reactions in a cooling magma, it should be borne in mind that sulphur and the halogens are minor constituents of the igneous rocks and would remain so if they were multiplied many fold. In all probability, therefore, they are minor constituents of the magma, and the thermal effects of reactions in which they take part must be correspondingly limited. Ferrous iron, it is true, reaches much higher values as a magmatic component, and when ferrous iron and water are both relatively high it may be that the reaction between them becomes important. There are magmas, on the other hand, very low in ferrous iron where the heat effect of this reaction must be trifling. On the whole it does not seem probable that very large stores of chemical energy are to be found in the gas reactions of a magma compared with the specific heat of the gas-free lava. It can not be denied, however, that other reactions in the melt, such as the association of hydrates or reactions between the non-volatile substances, may be of significance.

Whether large or small, all such thermal reactions would become effective only in the process of cooling. If they serve as an agency in the depths for heating cooler rocks or magma which contains similar gases in similar concentrations, it is obvious that this chemical energy would be practically balanced against the absorption of heat in the cooler rock; in the heating of a rock which had already lost much of its gas such a magma would be more effective.

The initiation of volcanic phenomena involves, of course, an abnormally high temperature at some locality in the earth's crust, but how this could be originally brought about through chemical

energy it is difficult to imagine. Magmatic intrusion seems to be a necessary preliminary and this demands the intervention of mechanical energy. At the best we seem to be driven to this position: So far as buried magma is concerned chemical energy may have considerable effect in increasing its heat capacity and prolonging the period of intrusive or eruptive activity, but in initiating the activity or in rejuvenating declining activity, it must from the nature of the case be ineffective.

Possibly it may be asked whether some reservation ought not to be made here because of the influence of high pressures on the equilibria in question. It is safe to answer that so long as the magma remains entirely liquid this factor is unimportant. Pressure causes a shift in equilibrium, to be sure, in the direction of diminishing volume, but since the density of the earth as a whole is only about twice the density of the average rock, and since the depth at which intrusion is supposed to take place is less than $\frac{1}{100}$ of the earth's radius, the magnitude of this volume change must be small.

So far we have kept in mind the magma in the *liquid state*. If crystallization [54] takes place the heat effects may be large, though this is not strictly a chemical change, and again it is induced by cooling. It is indeed conceivable that crystallization should be brought about *without cooling*. Suppose that a deep-seated magma entirely liquid were subjected to pressure as a result of contraction in the earth's crust. Crystallization might take place on account of decreased solubility of some mineral or minerals despite the rise in temperature which would inevitably follow compression. In that case a further heat effect would be obtained from the crystallization, but it will be observed here also that the intervention of mechanical energy is essential, so that even if we class crystallization as a chemical action, we need make no reservations respecting pressure in our conclusion regarding the part played by chemical energy in volcanism.

III. Heat from surface oxidation.

When the magma reaches the surface, oxidation of the combustible gases by air may play an important rôle in the volcanic phenomena. We have already seen that the extent of such oxida-

[54] For the latent heat of silicates see O. Mulert; *Z. anorg. Chem.*, **75**, 198, 1912; W. P. White: *Z. anorg. Chem.*, **69**, 348, 1911; *Am. Jour. Sci.*, **28**, 486, 1909.

tion necessarily depends on conditions at the crater. At Kilauea oxidation by the air appears to contribute a considerable amount of heat to the magma.

In 1912 Day and Shepherd [55] made the important observation that "when the gases given off by the lava increase in quantity, the quantity of the lava (lava-level in the basin) remaining the same, the temperature *increases*, and, conversely, when less gas is discharged through the lava, this temperature *diminishes again*." At the same time these authors found that "successive tubes (of gas) collected from the volcano at the same time do not show the individual gases to be present in the same proportions, but rather in proportions which change with every bubble which bursts from the liquid basin." In consequence of these observations they concluded that the lava was heated by a store of energy in the gases which were probably reacting with one another as they moved toward the surface and that they probably reached a maximum temperature at the top.

The subsequent work of Jaggar [56] has thrown much light on the observations of Day and Shepherd. It has already been explained in this paper in another connection (pp. 4 and 17) that Jaggar finds good evidence of the oxidation of combustible gases by air, through downward suction, when the level of the lake is falling, and by infalling surface crusts of lava which have absorbed air by reason of their vesicular nature. At the surface itself, careful observation reveals flames along the lava cracks.

If the heat effect of this oxidation is sufficiently great, the temperature ought to be highest at the upper surface of the molten lava. In January, 1917, Jaggar sounded the lava lake with a long iron pipe and found at two different points, one of them 30 feet from the shore, that the depth of the *thinner* lava was about 50 feet. At that depth, the pipe struck a layer too viscous for it to penetrate. A month later, when the lava lake subsided the shore line was found to be practically perpendicular, so that the impenetrable layer could not have been a part of a shelving shore. Further exploration of the lake revealed the fact that the temperatures were not only very variable but that they were no higher at a depth of several feet and that they reached their maxima where there was the most convincing evidence of rapid

[55] *Loc. cit.*, p. 601.

[56] *Am. J. Sci.*, **44**, 161, 1917.

oxidation. Thus the temperature of the lava under the surface crust of the lake, as determined by Seger cones in an iron pipe, was found to vary from 750° to 850°; in the "grottos," where rapid downward currents seemed to be drawing in air, the temperature rose above 1130°, and in the "blowing domes," which are built up of spattered lava through the agency of rapidly escaping gases, the temperatures reached 1250° to 1350° and were hottest where the gases came into contact with the outer air. Previous measurements by Shepherd and Perret had been made in "lava fountains"—points in the lake marked by a vigorous current of escaping gases. Here the temperature ranged from 1100° to 1185°.

Taking all the evidence together, Jaggar's case for surface oxidation at Kilauea is convincing. Probably the most important question we may ask concerning it is: *What proportion of the heat* is supplied in this way? It can hardly be supposed that the *principal* source of heat is from this cause; originally, of course, it could not have been so.

Little is known about surface combustion in volcanic craters generally. At Santorin, however, Fouqué [57] observed flames issuing from the crater in 1866, and his observation was confirmed by Schmidt.[58]

VI. VOLCANIC EXPLOSIONS.

Considerable diversity of opinion has been expressed on the cause of volcanic explosions. On the one hand, it has been held that they were the result of the sudden vaporization of vadose water or water included in the superficial strata of the earth, and on the other that they could only be caused by the expansion of gases which come from the magma itself.

I. Secondary explosions.

In the summer of 1902, while Mt. Pelée was in eruption, G. C. Curtis [59] observed on the Islands of Martinique and St. Vincent hundreds of explosions of various degrees of violence which were caused by the flow of rain water upon hot volcanic ejecta. This detritus, consisting of material all the way in size from dust to huge boulders, was piled up in the stream valleys in masses some-

[57] Santorin, Paris, 1867.

[58] "Vulkanstudien," p. 193, Leipzig, 1874.

[59] *Jour. Geol.*, xi, 199, 1903.

times 100 feet thick, the lower layers of which naturally preserved a high temperature for a long time. The explosions were brought about by the sudden flooding of the river beds by torrential tropical rains or by the rise of water following the caving in of ash beds which dammed up the stream channels.

Curtis saw at close range two eruptions of this sort of remarkable violence—one on the Sèche River, Martinique, and the other near the mouth of the Wallibou River, St. Vincent. The latter threw out a tremendous column of steam, ash and boulders to an estimated height of over 3000 feet. Some of the ash craters formed in this way were 40 feet deep by more than 160 feet in diameter. There is therefore no doubt that explosions of a purely secondary character, that is, due to the vaporization of surface water, and of great violence can and do occur under natural conditions.

Lacroix observed similar but less violent explosions at Martinique. Russell,[60] impressed especially by the evidence of Curtis, would explain tentatively all eruptive phenomena as the result of contact of the ground water with "highly heated rock rising from the depths of the earth." The peculiarly porous nature of many volcanic cones built up, as they often are, of porous and fragmental materials should make them exceptionally penetrable by water.

To what extent explosions in volcanoes are due to this cause is not yet known. A. L. Day[61] connects the explosions at Lassen Peak in 1914 and 1915 with the melting of the heavy snows which filled the former summit crater and which there attain great depth. To ascribe the activity of volcanoes of the Hawaiian or Strombolian type or even the "nuées ardentes" of Mt. Pelée to surface water alone (steam explosions) appears to stretch the hypotheses beyond the reach of any tangible support from existing records. Capillary phenomena (Daubrée effect) cease to be effective above the critical temperature of water and so appear to afford no aid in bringing ground water within the sphere of action of a column of liquid lava.

Gautier[62] holds an intermediate position between those who regard volcanic explosions as caused by the sudden contact of

[60] *National Geographic Mag.*, xiii, 416, 1902.

[61] Unpublished work.

[62] *Ann. des Mines*, (10) 9, 316, 1906, especially pp. 342, 368 and 369.

surface water and hot volcanic material and those who seek the cause of these explosions in the nature of the magma itself. He finds a necessary condition of all eruptive phenomena in the gases, especially the water, of the deep-seated rocks. Some of this water is a reduction product of the oxides in the magma by hydrogen from the depths of the globe, but another portion is supplied by descending meteoric waters which are taken up by rocks in place of the water they have already lost by volcanic heat.

The second essential condition of eruptive activity, according to Gautier, is the sudden access of heat to the plutonic rocks. This is brought about by a sudden subsidence of the earth's crust into the hot zone, thereby forcing molten lava into fissures of the plutonic rocks. The peculiar feature of Gautier's theory, *a sudden subsidence*, need not be considered here since it belongs to the mechanical side of the subject.

II. Primary explosions.

It is only in rare instances that much of scientific value has been learned from direct observation of volcanic explosions. The structure of pumice, one of the most characteristic products of explosion points clearly to the release of gas under pressure, while the torrential rains which so frequently accompany eruptive outbursts indicate the nature of the most important of the gases.[63] In view of all the evidence it seems impossible to avoid the conclusion that many of the major volcanic explosions are produced by gases direct from the magma, and that water is the chief of these gases.

If we entertain the hypothesis that explosions of this character are caused by the instantaneous oxidation of hydrogen or other combustible gas, it is impossible to conceive of conditions under which chemical action of this kind could proceed, for, while of course an abundant supply of combined oxygen exists in the magma itself, the conditions there are totally inadequate to effect a sudden union of the gases (p. 15). After a crater has once been opened, it is conceivable that combustible gases might be exploded with air. The proportion of the combustible constituents would have to be considerable. Not all volcanic gases could be exploded under any conditions unless we are wrong about the nature of the original gases. A further essential condition for explosion is that a mixture of the gas with air must be effected at a temperature *below*

[63] For an alternative view see p. 17.

the ignition point and that the mixture must subsequently be raised to that temperature. While this may be possible, it is difficult to picture such a thing in any convincing way. That large volumes of combustible gas may escape into the air and burn without explosion is a fact often manifested at gas wells.

Probably the best and most convincing evidence on the nature of primary volcanic explosions that we possess is the series of careful and systematic observations by Lacroix at Mt. Pelée in 1902–3. Here was an unusual opportunity and a rare observer. Phenomena like the following were witnessed repeatedly and studied by him in detail. The mouth of the crater at intervals roofed itself over with a dome of stiff viscous lava forced up from below. Lacroix tells us that the necessary and sufficient condition for the formation of a dome is that the lava should be very viscous. A dome is generally composed of highly siliceous rock, but a more basic and therefore more fusible lava would possess this essential characteristic at lower temperature. Pressure on the still incompletely solidified dome by the lava beneath it gradually thrust up a needle to a maximum height of hundreds of metres above the dome. Finally a sudden upthrust from below appeared to cause an explosive rupture of the shell and the projection of one of the remarkable red-hot clouds of gas, pumice and boulders which Lacroix describes so realistically. Lacroix[64] says that the only hypothesis which can be put forward to explain these explosions is a sudden expansion of gas beneath the shell of the dome. He believes that the most important of the gases is steam.

The effectiveness of steam as an explosive agent, long known to man, has been attested on a greater scale by the impressive evidence of Curtis. Captain Vernier, cited by Lacroix,[65] compares the disruptive force of steam at high temperatures with that of the high explosives. According to him one kilogram of water converted into steam at 1200° would exert a force sufficient to raise 391 kilograms of rock to a height of one kilometre.

Lacroix's keen observation, his painstaking labor in collecting facts, his judgment in sifting them and the many-sidedness of his effort have brought together a mass of testimony unrivalled for solidity in the annals of volcanology. Indeed it is doubtful

[64] "Montagne Pelée," p. 358.

[65] *Op. cit.*, p. 359.

whether *direct observation* of volcanic explosions will ever carry us much further. Of course many questions remain still unanswered, but Lacroix's conclusion in the case of Mt. Pelée that the crater explosions were caused by the expansion of magmatic gases, the chief of which is water, seems to me in accord with the best evidence we have on the nature and origin of the volcanic gases, and constitutes the best explanation of at least many major volcanic explosions.

In this brief survey the attempt has been made to give a general treatment of volcanism in its chemical aspects. While exceptions are not unlikely to occur in so complex a subject the following conclusions seem justified:

VII. SUMMARY.

1. The original volcanic gases can be traced back to the igneous rocks. Water is probably the most important of them.

2. The original volcanic gases are generally changed in composition by the time they reach the point of collection; in some cases they probably lose a portion of the strong acid gases; in most cases they become diluted by steam from surface water and by the atmospheric gases.

3. In some volcanic emanations the relations between the inert gases point to an atmospheric origin for these particular constituents; in others the inert constituents must either be of deep-seated origin or their original atmospheric relation has been changed by selective solubility in the magma.

4. Deville's laws respecting the variation in the composition of volcanic gases with the distance from an eruptive centre or with passing time are not supported by the great body of evidence.

5. There is evidence to show that a more or less abrupt evolution of gas from the magma occurs during crystallization, but it needs further support.

6. Chemical energy from shifting equilibria may have a considerable influence in prolonging the life of an eruption, but not in initiating or rejuvenating volcanic activity. Surface combustion in particular instances is probably an important factor in keeping up temperature.

7. Secondary volcanic explosions of great violence are undoubtedly produced by the access of surface water to hot volcanic ejecta. The primary explosions, according to the best evidence,

are the result of pressure from magmatic gases, not the result of chemical action.

ACKNOWLEDGMENTS.

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November, 1921.

APPENDIX.

THE ANALYSES OF VOLCANIC GASES.

A rather thorough search of the literature was made in the first place for the purpose of finding whether any relation whatever existed between the composition of volcanic gases and the temperature at which they issue from the ground. Then as the present paper at several points calls for the examination and comparison of the analyses of volcanic gases, it was thought best to bring the collected analyses together as an appendix to this article. F. W. Clarke [1] and F. von Wolff [2] have already brought together a considerable number of such analyses but neither collection approaches completeness. It was my first intention to include all analyses of volcanic gases in this compilation, but it soon became evident that there were many partial analyses which were not worth the space. Where a considerable number of analyses have been made in the same general locality at the same period, only representative ones are included. Otherwise it is believed that this collection is practically complete. Where a complete analysis of a gas, including the water, and a separate analysis of the fixed gases are both given in the literature, the latter analysis is generally included for purposes of comparison with other analyses

[1] "Geochemistry," *Bull. U. S. Geol. Survey*, 695, 1920, pp. 255-264.

[2] Vulcanismus (Stuttgart, 1914), Bd. I, pp. 555-560.

where the water is omitted. The analyses of gases from hot springs of well-known volcanic origin are here included as of importance in following out the volcanic processes to completion, so far as this is possible.

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ANALYSES OF VOLCANIC GASES.

HAWAII	Date	No.	Temp.	H_2O	CO_2	CO	CH_4	C_2H_6	C_2H_2[g]	H_2	Cl_2	F_2	H_2S	SO_2	SO_3	S_2	N_2	A	He	O_2
Fumarole, 150–200 metres N. of Crater.	1910	1	340	30	3.												67.[a]			
		2	340	8.5	15.3												76.2[a]			
Sulphur Bank 4 kilometres from Crater	1910	3	96		16.												84.[a]			
		4	96		33.												67.[a]			
		5	96		23.3												76.7[a]			
		6	96		10.7												89.3[a]			
		7	96		17.												83.[a]			
		8			23.8	5.6	none	none	none	7.2				none			63.3	none		
The Crater	May 1912	9			58.0	3.9	none	none	none	6.7				1.5			29.8	none		
		10			62.3	3.5	none	none	none	7.5				12.8			13.8	none		
		11			59.2	4.6	none	none	none	7.0				none			29.2	none		
		12			73.9	4.0	none	none	none	10.2				none			11.8	none		
The Crater	Dec. 1912	13		26.2[b]	49.6[b]						trace[b]	none[b]			none[b]		24.1[b]			
		14		26.6[b]	33.7[b]						none[b]	none[b]			7.6[b]		32.1[b]			
		15		29.7[b]	45.4[b]						trace[b]	none[b]			3.5[b]		21.3[b]			
		16		9.74[b]	3.64[b]										.37[b]		66.71[b]			19.54[b]
Devil's Kitchen	1912	17[d]			5.8						[.0513[e]]	[.0079[e]]			[1.328[e]]		76.0			18.2
		18[e]		25.49[b]	8.12[b]						[.0298[e]]	none[e]			.59[b]		51.20[b]			14.58[b]
100 metres S. of auto road terminal	1912	19		7.81[b]	9.64[b]						none				0.51[b]		63.85[b]			18.18[b]
		20		67.99	2.65	1.04				4.22	udt			.16		.70	23.22	udt		
		21		38.48	17.95	.36				1.35	udt			3.51		.49	37.84	udt		
		22		17.97	33.48	1.42				1.56	.17			29.83		1.79	12.88	.45		
		23		77.50	11.12	3.92				1.42	.02			—		8.61	—	.51		
The Crater	1917	24		64.71	9.54	1.12				1.53	—			9.90		2.72	10.47	—		
		25		89.77	1.97	.82				.21	—			.95		2.70	3.50	.07		
		26		64.18	17.25	.62				.76	.25			9.75		1.07	5.88	.18		
		27		75.08	15.27	.45				.70	—			6.98		.49	.87	.14		
		28		59.07	8.37	.82				1.82	1.01			16.80		2.48	8.92	.29		
		29		80.93	1.54	.43				.37	1.34			—		3.56	2.44	.39		
		30		75.09	5.79	.00				.00	4.08			4.76	2.41	.00	7.92	udt		
		31		80.31	6.63	.22				.15	1.11			3.23	5.51	.00	2.37	.56		
		32		84.98	6.79	.14				.17	.62			1.38	3.43	.15	2.33	.00		
		33		78.71	.87	.16				.07	.03			0.01	.13	.00	20.01	.00		
		34		36.18	47.68	1.46				.48	.04			11.15	.42	.04	2.41	.14		
		35		50.88	16.44	.11				.10	.03			13.57	3.56	.05	15.03	.21		
The Crater	1919	36		61.56	20.03	.50				.32	.00			11.42	.55	.25	4.13	.31		
		37		97.09	1.42	.05				.08	.03			.51	.00	.07	.68	.05		
		38		67.52	16.96	.58				.96	.10			7.91	2.46	.09	3.35	.66		
		39		76.84	14.81	.47				.17	.00			3.65	1.03	.10	2.91	.00		
		40		73.89	11.53	.13				.19	.10			6.14	1.70	.03	6.20	.16		
		41		66.25	18.03	.56				.67	.08			8.53	2.53	.15	3.11	.08		
		42		79.31	11.61	.37				.58	.05			6.48	.00	.24	1.29	.04		
		43		61.88	17.55	.74				.83	.13			10.81	3.22	.22	4.50	.12		
Mauna Loa Lava Flow	Oct. 1919	44		75.44	3.84	.03				—	—			1.22	2.08	—	10.80	.58		
		45		67.43	6.42	.19				.01	—			1.95	8.12	—	15.39	.42		

ANALYSES OF VOLCANIC GASES—*Continued.*

VESUVIUS	Date	No.	Temp.	H_2O	CO_2	CO	CH_4	C_2H_6	C_2H_4[g]	H_2	HCl	HF	H_2S	SO_2	SO_3	S_2	N_2	A	He	O_2
East edge of Great Crater of 1850	1856	46	154°	considerable proportion	none						present			2.6	present		78.7			18.7
N. W. of small cavity of 1850	1856	47	154		none						present			2.4	present		77.9			19.7
N. E. rim of Great Crater of 1850.	1856	48	66-70		none									1.7			78.0			20.3
Gulf of 1854	1856	49	74		none									.7			79.8			19.5
	1856	50	74											2.6			78.5			18.9
Centre of Plain	1855	51	89		9.52								none				72.32			18.16
End of small lava flows of 1842-1848	1856	52	60		1.3								none				78.7			20.0
N. W. of smallest excavation of 1850	1856	53	67		3.45								none				77.30			19.25
Edge of Great Crater	1865	54	90		4.80												75.60			19.60
Near summit of cone	1906	55	300+	67.74	11.03	none	none			1.24	0.78		none	none			15.49[f]			3.72
	1906	56	300+	62.44	6.68	none	none			trace	trace		none	none			24.88[f]			6.0
Valley N. E. of Crater	1907	57	280–300	72.69	0.80	.15	none			.54	none		none	none			21.23			4.59
Same fumarole as No. 57	1907	58	280–300	77.76	0.66	.02	?			.02	none		none	none			17.62	.243		3.68
PHLEGREAN FIELDS																				
Torre del Greco	1865	59			85.38		.95		.05				none				9.38			2.85
Torre del Greco, flow of 1694	1869	60			90.2		2.8						none				6.2			0.8

a. Includes oxygen.
b. By weight.
c. Grams in water condensed in separate sample.
d. No ammonia in the water condensed.
e. Sulphur trioxide, 0.656 gram in separate sample of water in which chlorine and fluorine were sought.
f. Includes argon, etc.
g. Includes all unsaturated hydrocarbons.

ANALYSES OF VOLCANIC GASES—*Continued.*

PHLEGREAN FIELDS—*Cont'd*	Date	No.	Temp.	H_2O	CO_2	CO	CH_4	C_2H_6	C_2H_4[f]	H_2	HCl	HF	H_2S	SO_2	SO_2	S_2	N_2	A	He	O_2
Santa Lucia	1865	61			95.66								trace				4.34[b]			
Chiatamone	1865	62			65.34		3.22		.94				trace				22.53			8.52
Chiatamone	1869	63	27.2		82.1												16.2			1.7
Grotta di Zolfo	1865	64			94.42		.08		0.88				trace				2.45			1.11
Grotta di Zolfo, exterior	1869	65	27.0		87.7								5.0				6.5[i]			0.8
Grotta di Zolfo, interior	1869	66			87.8								5.7				5 7			0.7
Grotta di Zolfo	1869	67			92.3[j]		4.3										2.7			0.5
Great Solfatare of Pouzzoles.	1856	68	88-92	enormous mass	5.7									none			75.9			18.4
Great Solfatare of Pouzzoles.	1856	69	88-92	enormous mass	0.7									6.8			92.5[a]			
Great Solfatare of Pouzzoles.	1856	70	88-92	enormous mass	none		none	none	none	none				24.7			60.8			14.5
Great Solfatare of 1867.	1869	71	115		88.8								7.0				4.5			0.7
Little Solfatare, Orifice 2.	1856	72	93-93.5	extremely aqueous	2.9								none at lab.				78.85			18.25
Little Solfatare, Orifice 2.	1856	73	72-76	extremely aqueous	19.2								none at lab.				64.6			16.2
Little Solfatare, Orifice 3.	1856	74	90-91	extremely aqueous	30.5								none at lab.				60.6			8.9
Little Solfatare of Pouzzoles.	1865	75	96		56.67								11.43				26.18			5.72
Little Solfatare of Pouzzoles.	1865	76	77.5		15.09								none				69.40			15.51
Lago d'Agnano. Orifice 1.	1856	77	71-87		7.25								positive test				73.53			19.22
Stufe de San Germano, Orifice 1.	1856	78	83-93		3.3								positive test				76.6			20.1
Stufe de San Germano, Orifice 2.	1856	79	72-80.7		14.52		none	none	none	none			positive test				67.83			17.65
Lago d'Agnano.	1907	80		96-97	96.52		.12			.015							2.87	.028		0.46
Lago d'Agnano.	1856	81	29		67.1	none											26.4			6.5
Grotte du Chien	1856	82	29		73.6												21.1			5.3
Lago d'Agnano.	1856	83	32		81.1												15.1			3.8
Grotte d'Ammoniac.	1865	84			97.47												2.01			.52
Spring, Acqua Media.	1865	85			47.67								trace				52.33			none
Spring, Acqua Media.	1869	86	25		70.8								trace				29.6			0.6

ANALYSES OF VOLCANIC GASES—*Continued.*

PHLEGREAN FIELDS—*Cont'd*	Date.	No.	Temp.	H_2O	CO_2	CO	CH_4	C_2H_4	C_2H_4[e]	H_2	HCl	HF	H_2S	SO_2	SO_3	S_2	N_2	A	He	O_2
Acqua ferrata del Pozillo.	1865	87			36.21												63.79			
	1869	88	27		29.1								none				70.2			0.7
Spring Soforo ferrata.	1865	89			33.65								trace				66.35			none
Acqua ferrata e solforea (same as 89?)	1869	90	26		44.4								3.1				52.2			0.2
Telese Baths	1869	91	24		90.4								5.1				4.0			0.5
ETNA																				
Rim of upper Crater.	1856	92*	99								94.2		positive test	5.8	present					
Crater B, fumarole.	1865	93			5.0								.45				77.28			17.27
Crater D, fumarole.	1865	94			1.61								.35				79.07			18.97
Initial fissure of 1838.	1856	95	41–82.5	about 80%	12.1												73.1			14.8
	1856	96	41–82.5		9.3												90.70			
Fumarole on fissure.	1863	97	150–180		50.5								11.9				30.5			7.1
	1864	98	150–180		48.9								10.6				35.0			5.5
(Same day as No. 99.)	1865	99	150–180		66.2								12.7				16.7			4.4
	1865	100	150–180		32.0								6.4				51.8			9.8
(Same day as No. 99.)	1865	101	150–180		37.8								5.4				47.2			9.6
SICILY																				
Salinelle of Paterno Acqua Rossa.	1856	102	19.8		97.9												2.16			
	1856	103	19.8		93.23	none	none	none	none	none							5.8			0.97
	1865	104			97.9												1.70			.40
Paterno Val Corrente	1856	105			67.0	32.49[k]														.51
Acqua Rossa of Val Corrente.	1865	106			99.07												.75			.18
Mud volcano Val Corrente or San Biagio.	1865	107			74.99		3.77			0.99			none				19.47			2.78
Salinelle of Paterno.	1856	108			90.7		5.0										3.3			1.0
	1865	109			95.35		1.12			.50			none				2.94			.58
Salinelle of Paterno (average of several).	1865	110	ordinary		95.42		.96			.55			none				2.97			.77
	1865	111	27-46		92.53		1.49			.99			.30				4.70			.12
Paterno, Spring of Valancella.	1856	112			99.2												.8			none
	1865	113			99.78												.18			.04
Lago Palici.	1856	114			94.7		.68										3.52			1.1
	1865	115			93.49		1.45			.43							5.14			0.68

*This analysis includes only gases absorbed by NaOH.
f. Includes argon, etc.
h. Includes marsh gas and oxygen.
i. Includes methane.
i. Includes hydrogen sulphide.
k. Includes little hydrocarbon.

ANALYSES OF VOLCANIC GASES—*Continued.*

SICILY	Date	No.	Temp.	H_2O	CO_2	CO	CH_4	C_2H_4	C_2H_6	H_2	HCl	HF	H_2S	SO_2	SO_3	S_2	N_2	A	He	O_2
Macuba of Xirbi	1856	116			.93		97.95										1.12			
	1865	117			.70		73.73			trace							20.40			5.17
Small cone of Terrapilata.	1856	118			6.34		93.66										none			
	1865	119			0.26		40.98			trace							46.46			12.30
	1865	120			1.8												98.2			none
Acqua Santa of Limosina.	1856	121			1.6												98.4			none
	1865	122			2.10								none				96.60			1.30
	1866	123			4.35												88.70			6.95
Macluba of Girgenti.	1856	124			1.15		90.4										6.75			1.70
	1865	125			1.65		87.23			5.74			none				3.74			0.69
Spring of Santa Venerina.	1856	126	22.7		3.1		95.5[l]						0.2							1.2
	1856	127	22.7		4.2		83.62										12.18			none
	1865	128			3.13		71.76			3.70			trace				22.15			1.18
Spring of Segeste.	1865	129			.32								trace				88.12			11.56
LIPARI ISLES *Vulcano*											posi-tive									
Bottom of crater.	1856	130			none						test			21.3			63.63			15.07
	1856	131			none						none			27.50			58.48			14.02
North Slope.	1856	132	94		none									84.2			15.8[k]			
	1856	133	94		none									69.6			24.9			5.5
Acqua Bollente.	1856	134	82		9.8								82.8				6.8			0.6
	1856	135	84		2.5									89.6			7.9[k]			
	1856	136	25		86.0												13.6			0.4
Near Chem. Works.	1856	137	25		83.0												17.0			none
	1856	138	25		86.0												14.0			none
Interior of Great Crater.	1865	139	360+		23.40						73.8[m]						2.28			.52
Interior of Great Crater.	1865	140	250		22.0						66.0[m]						9.6			2.4
Interior of Great Crater.	1865	141	150		59.62						27.19[m]						10.99			2.20
Interior of Great Crater.	1865	142	100		68.8						7.3		10.7				11.2			2.7
Interior of Great Crater. (Same as Acqua Bollente).	1865	143	100		63.59						none		trace				29.13			7.28
Small pool near the sea.	1865	144	86		77.02								17.55				4.73			.70
Seashore near No. 144.	1865	145	—		97.12								trace				2.40			.48

ANALYSES OF VOLCANIC GASES—*Continued.*

SICILY *Continued*	Date	No.	Temp.	H_2O	CO_2	CO	CH_4	C_2H_6	C_2H_4	H_2	HCl	HF	H_2S	SO_2	SO_3	S_2	N_2	A	He	O_2
50 metres from No. 144.	1865	146			86.76								trace				11.35			1.89
200 metres from No. 144.	1865	147			72.34								none				25.53			2.13
250 metres from No. 144.	1865	148			38.79								none				57.42			3.79
Panaria Near seashore.	1865	149			90.53								6.44				2.51			0.52
Small lagoon.	1865	150			97.0								trace				2.51			0.49
Bottaro between Stromboli and Lipari.	1865	151			72.3								trace				22.6			5.1
SANTORIN																				
Near Isle of Beka	1866	152	50-66		1.49		.42			none			trace				79.64			18.45
Palaea-Kaméni St. Nicholas.	1866	153	19		78.44		.64			none			none				17.55			3.37
	1866	154	69		50.41		2.95			16.12			trace				30.32			0.20
Nea-Kaméni.	1866	155	65		90.78								trace				8.34			.88
	1866	156	56		95.37								trace				4.14			.49
Pool between Nea-Kaméni and Aphroessa.	1866	157	50		86.76								trace				11.23			2.01
	1866	158	50		84.85								trace				12.84			2.31
Between Aphroessa and a point S. E. of Nea-Kaméni.	1866	159	61		35.60		.81			30.09			trace				32.04			1.46
Near N. bank of Aphroessa.	1866	160	60		0.07		.71			1.62			trace				76.04			21.56
West slope of George.	1866	161	160	considerable	17.28		.49			trace			1.64				66.47			14.12
Foot of cone of George.	1866	162	87	considerable	5.88								.42				74.71			18.99
	1866	163	122	considerable	12.24								.90				70.45			16.41
Between George and Aphroessa.	1866	164	73		37.04		.43			27.10			trace				35.02			.41
	1866	165	75		37.24		.47			28.12			trace				33.66			.51
	1866	166	78		36.42		.86			29.43			trace				32.97			.32
	1869	167	60		90.0		trace			none			none				9.1			0.9
Port of Vulcano.	1870	168	55		87.0		trace			none			none				13.0			none
	1870	169	49		77.3		trace			none			none				22.6			none
	1870	170	49		97.1		trace			none			none				2.9			none
	1871	171	49		95.9		trace			none			none				3.4			0.5
	1870	172			37.5												60.8			1.7
	1870	173	46		78.0												21.5			0.5
	1869	174	30		86.0												13.0			1.0
	1870	175	28		43.7												53.6			2.7

l. Includes nitrogen.

m. Includes sulphur dioxide.

ANALYSES OF VOLCANIC GASES—*Continued.*

SANTORIN *Continued*	Date	No.	Temp.	H_2O	CO_2	CO	CH_4	C_2H_2	C_2H_4	H_2	HCl	HF	H_2S	SO_2	SO_3	S_2	N_2	A	He	O_2
Port of George.	1870	176	19		98.8		trace			none			trace				1.8			0.4
Base of cone of George	1870	177			63.3		0.5			0.8							28.6			6.5
200 metres from cone of George.	1870	178	115		68.5						19.4			12.0						
Ravine between Cone of George and lava flow.	1870	179	110		98.5						1.0			0.4						
Port of St. Nicholas.	1870	180	30		97.6		0.1			none			none				1.9			0.4
GRECIAN ARCHIPELAGO																				
Nisyros, old volcano, adventitious fumarole.	1873	181			97.5[j]		1.0			trace							1.5			
	1873	182			38.4		0.4			1.5			57.1				2.4			
RUSSIA																				
KERTSCH PENINSULA (CRIMEA) 183-193 Mud Volcanoes.																				
Titarowka. Taman Peninsula.		183			3.5	—	92.24	—	4.26	—			—				—			—
Baladsary.		184[n]			0.2	1.0	80.6	.0	.0	10.2			trace				6.0			2.0
		185[n]			3.7	3.0	64.7	.0	4.2	15.4			trace				4.0			0.9
		186[n]			6.0	.0	18.86	15.3	3.7	.0			trace				53.5			2.2
		187[n]			4.8	0.6	53.5	.0	.0	.0			0.25				41.05			0.8
Bosdag.		188			3.0	1.0	53.3	.0	.8	.0			.0				35.7			5.3
Arbat.		189[n]			4.8	1.2	81.6	.0	1.0	.6			.0				10.4			1.0
Adsi Kabul.		190[n]			4.4	3.6	50.05	.0	2.2	.0			trace				34.4			5.4
Keljany.		191[n]			4.0	.0	76.05	.0	0.4	.0			.31				18.89			0.2
Marassy.		192[n]			.28	.0	41.3	45.6	0.28	.0			trace				9.68			2.86
		193[n]			1.0	.0	52.2	5.0	.0	.8			.0				39.7			1.3
TRANSCAUCASIA																				
Baku. Sacred Fire.		194[o]			1.7		88.0	4.6									4.3			0.6
	1902	195	327-419	saturated	16.80[p]					11.60[q]							59.20[r]			11.60
WEST INDIES	1902	196	327-419	saturated	13.58[p]					11.00[q]							64.10[r]			11.11
Martinique, Mt.	1902	197	327-419	saturated	16.42[p]					10.64[q]							60.53[r]			12.14
Pelée, River	1902	198	327-419	saturated	15.38[p]					15.30[q]							55.65[r]			13.67
Blanche.	1902	199	327-419	saturated	15.38	1.60	5.46		none	8.12	trace		none			trace	54.94	0.71		13.67

ANALYSES OF VOLCANIC GASES—*Continued.*

WEST INDIES *Continued.*	Date	No.	Temp.	H_2O	CO_2	CO	CH_4	C_2H_6	C_2H_4	H_2	HCl	HF	H_2S	SO_2	SO_3	S_2	N_2	A	He	O_2
Guadeloupe. Fumarole of the North.	1904	200	96	saturated	52.8	none	none	none	none		trace		2.7			trace	36.07	.73		7.5
Guadeloupe Fumarole Napoleon	1904	201	—	saturated	69.5	none	none	none	none	none	none		4.5			trace	22.32	.68		2.7
COLOMBIA, S. AMERICA.																				
Mud volcano. Turbaco, near Cartagena.	1868	202			4.1		72.5	7.8		0.4										3.2
	1868	203					100.													
Mud volcano. Turbaco, near Cartagena.	1868	204			1.5		97.6	0.5												
	1868	205					98.7			0.3										
Mud volcano del Tigre.	1868	206					100.													
	1868	207					93.8	1.8												1.0
Puracé Crater.	1868	208	86.6		2.1									none						12.9
Puracé Solfatara.	1868	209		much	98.2									0.4						
Puracé Solfatara.	1868	210			95.6									0.3						0.6
Puracé Hot Spring.	1868	211			83.6								13.9							0.5
Azufral Springs.	1868	212			84.9								9.4							
	1868	213			80.5								8.8							
	1868	214			87.1								11.6							
Ecuador Boundary. Boca del Mundo.	1868	215		59.1	33.3								5.9							0.3
ICELAND																				
Hekla lava flows of 1845.	1846	216			1.01	none	none				none		none	none			78.90			20.09
Krisuvik solfatara	1846	217			87.43	none	none			4.30			6.60				1.67			
Same gas as 217.	1846	218		82.3	15.47	none	none			.76			1.17				.30			
Krisuvik, 2d fumarole.	1846	219			88.24	none	none			4.10			6.97				.69			
½ league from Krisuvik.	1846	220			79.07	none	none			4.72			15.71				.50			
Krisuvik, small puddles.	1846	221			88.54	none	none			7.87			1.79				1.80			
	1846	222			86.92	none	none			8.36			3.28				1.44			
Haukadalr, Great Geyser.	1846	223			8.92	none	none			6.59			0.38				84.11			none
Hekla, Great Crater, 1st fumarole.	1846	224			2.44	none	none				none		none	1.54			81.81			14.21

n. Traces of phosphine were found in Nos. 185, 189, 190; but none in Nos. 184, 186, 187, 191, 192, 193.
o. Contains vapors, 0.8
p. Absorbed by caustic potash.
q. Combustible gas.

ANALYSES OF VOLCANIC GASES—*Continued*.

ICELAND *Continued.*	Date	No.	Temp.	H_2O	CO_2	CO	CH_4	C_2H_6	C_2H_4?	H_2	HCl	HF	H_2S	SO_2	SO_3	S_2	N_2	A	He	O_2
2nd fumarole.	1846	225			.56	none	none				none		none	none			82.58			16.86
Krisuvik fumarole	1871	226															81.0			19.0
Krisuvik fumarole	1871	227		99.7													.24			.06
Krisuvik fumarole (2nd sample.)	1871	228															80.65			19.35
Myvatns, Oraefi, lava fissure.	1876	229			3.40												77.35			19.25
Krisuvik, solfatara.	1871	230			46.25					5.52			46.86				1.37			
Krabla, N. E. of Myvatns solfatara.	1871	231			68.80					15.59			5.89				9.72			
Krabla a second solfatara.	1871	232			63.52					11.71			13.94				10.83			
Krabla, a second solfatara.	1871	233			71.99					9.30			14.55				4.16			
Krabla, a second solfatara.	1871	234		99.6000	.2850					.0372			0.582				.0166			
Reykjahlid (or Námafjeld) solfatara.	1876	235			59.24					7.94			26.32				6.50			
Reykjahlid mud-pool.	1871	236			44.97					25.49			15.78				13.76			
Reykjahlid mud-pool.	1871	237			52.00					27.02			19.26				1.72			
Reykjahlid mud-pool.	1871	238		98.5	.78					.40			.29				.03			
Reykjahlid mud-pool.	1876	239			47.59					28.53			21.64				2.24			
Reykjahlid mud-pool.	1876	240			48.58					27.82			21.85				1.75			
Reykjahlid mud-pool.	1876	241			70.36					27.73							1.91			
Krafla No. 1.	1906	242	86		80.9		none			3.5			12.6				3.0[f]			none
Krafla No. 2.	1906	243	82		73.5		none			9.3			13.9				3.3[f]			none
Námafjall No. 1.	1906	244	76		37.5		none			49.0			2.2				5.9[f]			none
Námafjall No. 4.	1906	245	90		30.0					none			18.4				2.6[f]			none
Reykjahlid No. 1	1906	246	44		.02		none			none			none				78.9			21.1
Reykir No. 1.	1906	247	62		none		none			none			none				98.49	1.48	.0132	none
Reykir No. 2.	1906	248	66.5		none		none			none			none				98.36	1.60	.0140	none
Reykir No. 3.	1906	249	64.2		none		none			none			none				100.[f]			none
Reykir No. 4.	1906	250	65		none		none			none			none				100.[f]			none
Reykir No. 5.	1906	251	17.3		none		none			none			none				98.34	1.61	.0146	none
Hveravellir No. 2	1906	252	95		79.5		0.9			none			2.8				16.5	.294	.0050	none
Hveravellir No. 10	1906	253	77		44.9		1.4			none			none				46.7[f]			7.0
Hveravellir No. 27	1906	254	82		40.0		1.5			none			none				51.5[f]			7.0
Hveravellir No. 16	1906	255	93.5		46.7		1.5			0.7			none				45.7[f]			5.4
Hveravellir No. 25	1906	256	81		77.8		1.0			none			none				20.6	.441	.0063	0.2

ICELAND *Continued*	Date	No.	Temp.	H_2O	CO_2	CO	CH_4	C_2H_6	C_2H_4[s]	H_2	HCl	HF	H_2S	SO_2	SO_3	S_2	N_2	A	He	O_2
Kjaðlraun No. 2.	1906	257	88		0.1		none			none			none							
Kerlingarfjöll No. 2.	1906	258	92		71.1		0.3			11.7			14.4				79.2[f]			20.7
Kerlingarfjöll No. 3.	1906	259	94		66.9		0.9			21.7			7.4				2.5[f]			none
Kerlingarfjöll No. 4.	1906	260	94.5		70.7		0.7			14.5			13.1				3.1[f] 1.0[f]			none none
Grafarbakki No. 1	1906	261	95		6.4		0.8			none			none				90.0	1.68	.0104	1.1
Grafarbakki No. 2	1906	262	97.5		3.7		0.6			none			0.1				93.4	2.15	.0105	none
Grafarbakki No. 3	1906	263	97.		1.3		0.9			none			none				97.7[f]			0.1
Laugarás No. 1	1906	264	95.		none		0.7			none			none				97.4	1.93	.0104	none
Laugarás No. 2	1906	265	98.5		none		0.7			none			none				99.3[f]			none
Laugarás No. 3	1906	266	93		none		0.5			none			none				97.4	2.1	—	none
Reykjafoss No. 1	1906	267	93		27.0		0.2			2.5			none				67.9	1.36	.0103	1.0
Reykjafoss No. 2	1906	268	94		87.9		0.3			0.6			6.7				4.5[f]			none
Reykjafoss No. 3	1906	269	95		85.6		0.3			1.4			5.7				7.0[f]			none
Reykjafoss No. 4	1906	270	99.4		84.5		0.2			none			12.0				3.3[f]			none
Hengill No. 1	1906	271	94.5		73.4		0.3			13.5			11.0				1.8	.0113	.00059	none
Hengill No. 2	1906	272	75.5		79.7		0.4			13.2			3.9				2.7[f]			none
Hengill No. 3	1906	273	91		67.0		0.6			17.2			11.2				3.9	.088	.0020	none
Hengill No. 4	1906	274	97		72.0		0.9			16.4			7.4				3.3[f]			none
KATMAI		275	95	99.97	.005	.000	.000						.007[s]				.017[f]			.001
Ten Thousand Smokes.[r]		275a			17.5	.5	.2						23.6[s]				57.1[f]			1.1
		276	244	99.99	.004	.000	.000						.002[s]				.003[f]			.000
		276a		—	40.7	.1	.2						23.0[s]				35.5[f]			0.5
		277		99.93	.042	.000	.000						.010[s]				.018[f]			.000
		277a			59.7	.2	.1						14.2[s]				25.0[f]			0.8
Lower Valley.	1919	278	255	99.96	.015	.000	.000						.010[s]				.015[f]			.000
		278a		—	35.9	.2	.1						24.7[s]				37.4[f]			0.7
		279	177	99.96	.003	.000	.000						.019[s]				.018[f]			.000
		279a		—	6.8	.1	.0						47.2[s]				46.0[f]			0.0
		280	98	99.95	.004	.000	.000						.021[s]				.024[f]			.000
		280a		—	8.6	.2	.1						43.2[s]				47.7[f]			0.2
		281	251	99.60	.000	.000	.000						.000[s]				.311[f]			.083
		281a		—	0.2	.0	.2						1.0[s]				77.9[f]			20.7
		282	244	99.91	.017	.000														.001
		282a		—	18.6	.8														1.0
		283	403	99.90	.038	.000	.007						.025[s]				.024	.000		.005
		283a			38.1	.6	7.1						24.7[s]				24.09	.31		5.1
Nova Rupta Basin.	1919	284	414	99.91	.018	.000	.002						.028[s]				.009	.000		.001
		284a		—	30.8	.6	3.6						47.1[s]				15.73	.17		2.0
		285	290	99.40	.432	.000	.068						.042[s]				.049	.000		.006
		285a		—	72.0	.2	11.4						7.2[s]				8.10	.10		1.0
		286	238	98.60	.986	.008	.169						.045[s]				.179[f]			.014
		286a			70.4	.6	12.1						3.2				12.8[f]			1.0

r. All analyses marked with *numbers only* (275-291) will be seen to include water, while those marked a are analyses of the fixed gases corresponding. Thus, 275a is an analysis of the fixed gas of 275. These analyses are recorded separately for comparison with analyses so frequently occurring in the literature in which no account of the water is taken.

s. Includes hydrogen.

ANALYSES OF VOLCANIC GASES—*Continued.*

KATMAI *Ten Thousand Smokes*	Date	No.	Temp.	H_2O	CO_2	CO	CH_4	C_2H_2	C_2H_4	H_2	HCl	HF	H_2S	SO_2	SO_3	S_2	N_2	A	He	O_2
Upper Valley.	1919	287	96	99.95	.007	.000	.000						.035[s]				.006	,000		0.000
		287a		—	14.8	.6	1.1						79.9[s]				11.62	.18		.8
		288	253	99.96	.008	.009	.000						.027[s]				.004	.000		.000
		288a		—	20.6	.2	.6						67.9[s]				9.48	.12		1.1
Broken Mt. Valley.	1919	289	122	99.70	.011	.000	.000						.020[s]				.268	.000		.000
		289a		—	3.6	.1	.0						6.7[s]				88.41	.99		0.2
		290	98	99.94	.006	.000	.000						.051[s]				.002	.000		.000
Knife Creek Valley.	1919	290a		—	10.2	.2	.6						84.7[s]				3.95	.05		0.3
		291	440	99.96	.013	.000	.001						.022[s]				.004	.000		.000
		291a		—	33.6	.8	1.9						53.9[s]				9.26	.14		0.4
(Approximate Determinations[t]) Ten Thousand Smokes.	1917	292									0.006	0.003	0.006							
		293									.006									
		294									.024	.003	.0007							
		295									.057	.052	.016							
		296									.282	.041	.092							
		297									.083	.024	.008							
		298									.086	.029	.012							
		299									.013	.005	.006							
		300									.136									
		301									.042	.081	.077							
		302									.059	.033	.012							
		303									.008	.006	.022							
		304									.566	.099	.095							
		305										.003	.017							
		306									.241	.041	.026							
		307									.150	.033	.017							
CANARY ISLANDS																				
Pico de Teyde north fumarole.	1907	308	83		70.8												24.1[u]			5.1
		309	83		63.9												31.3[u]			4.8
		310	83		63.9												31.9[u]			4.2
Pico de Teyde South fumarole.	1907	311	83		67.6												28.8[u]			3.6
		312	83		70.1												25.8[u]			4.1
		313	83		71.1												26.9[u]			2.0
AZORES The Sea Near Island of Terceira.	1867	314			2.27		16.75			.32							68.45			12.21
JAVA Papandajan same fumarole.	1908	315			16.8									46.7			31.4			5.1
		316	192		24.									30.			38.			8.
		317			10.									26.			51.[v]			13.
		318			17.									20.			63[a]			

t. Water is taken into account in these determinations. They are comparable with the determinations in Nos. 275-291.
u. Includes other unabsorbable gases.
v. Water condensed from this fumarole contained 4.630 g. per liter hydrochloric acid; also some ammonium chloride. No H_2SO_4.

SOME APPLICATIONS OF THE MICROSCOPE IN RESEARCH.*

BY

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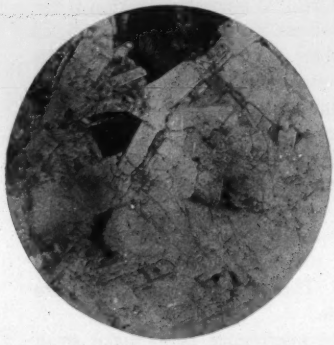
THE microscope in its present form is one of the most perfect and useful instruments available in research. Its construction may be said to date from the closing years of the seventeenth century, although the general idea of magnification by curved glasses and mirrors was applied long before. While magnification is the basis of the instrument, its usefulness would be much restricted if that property alone was available. Newton's discovery of the composite nature of light gave a strong impetus to both practical study and theoretic suggestion in connection with all forms of optical instruments. Newton believed that refraction and dispersion were commensurate in all cases, and declared that it was impossible to construct a lens which would produce a colorless image. It was discovered, however, that substances of the same refractive often have different dispersive powers and Dolland was able to construct a lens capable of forming a colorless image of an object illuminated by white light. These " achromatic " lenses are now part of all microscopic outfits.

The essential function of the microscope is to make small objects visible to the human eye, but *definition*, that is, the clear indication of form and structure, is also essential, and the later work of improving the microscope is directed especially to securing this. It has been accomplished partly by improvements in lenses, but largely by modifications in the nature of the light and the method of applying it. The most simple modification is that of changing the direction of the beam that illuminates the object to be examined. The natural way, which was at first used, is to allow the beam to pass directly through the object, that is, perpendicular to it, or to fall upon the surface at a similar angle. By passing the ray obliquely, or concentrating it as a cone centering

* Abstract of a paper presented at a meeting of the Section of Physics and Chemistry held Thursday, October 27, 1921.

in the object, shadow effects are produced which are often very satisfactory.

The application of photography to microscopy has been of great service, as it not only permits of permanent record of the field, but as the photographic plate has a different sensitiveness to light than has the human eye, differences of structure will be brought out by this means that the unaided eye would overlook. The ordinary photographic emulsions are not sensitive to green, yellow or red light. By special methods this sensitiveness may be extended so that a strong light of any color will affect the plate. Using plates of wide range of sensitiveness, color screens can be



Section of dolerite × 30. White light.

Section of dolerite × 30. Red screen.

inserted by which excellent results are often secured. Another modification of light which has been of immense advantage in all fields of optics is polarization. The term is applied to modifications of light by which it becomes much more sensitive to structure so that differences wholly inappreciable to the unassisted eye are brought out clearly. These differences are often indicated by brilliant colors, so that the several parts of the object are not only clearly indicated but the color contrasts are striking and often beautiful.

Another direction in which the service of the microscope has been advanced is in the preparation of the object. Many methods for this purpose are employed. One of the most used is sectioning, that is, cutting the specimen into thin layers. In the case of

animal and vegetable structures this is comparatively easy, and has been employed from an early period, but mineral structures are more difficult to handle. Sorby, a British scientist, developed about the middle of the last century the method of grinding minerals so thin as to be transparent, and laid the foundation of the science of petrology, which has become of great importance in mineralogy and geology. In the case of metals no amount of cutting will render them transparent to ordinary light, but many important data have been obtained by examining flat surfaces before and after etching. A special department of industrial microscopy—metallography—has grown up by aid of the methods of which the minute structure of commercial metals and alloys are capable of elucidation.

The microscope has found extensive and useful application in medico-legal work. Its revelations are often surprising and sometimes border on the humorous, because of the results being so different from what was assumed. During the late war cases of admixture of powdered glass with food were occasionally alleged. No case in which such a charge was substantiated seems to have been established, but several investigators have reported the actual facts. In one case crystals of ammonium magnesium phosphate were found; in another, in which it was suspected that grape-jelly had been so adulterated, the analyst (Doctor LaWall) found that the substance was merely cream of tartar (acid potassium tartrate) in comparatively large crystals. The client, however, was firm in his opinion, and it was not until the analyst dissolved some of the material in hot water that he was convinced it was not glass.

Messrs. Zoller and Williams, of the United States Bureau of Agriculture, recently reported a case of "sandy" ice cream, which on microscopic examination was found to owe its grittiness to numerous crystals of milk sugar. Commercial white arsenic (arsenous acid), the common poison, is found in two forms, a glassy or porcelain-like mass and a gritty powder. The latter generally shows distinct crystals, visible under moderately high powers, the particular form being the regular octahedron, but much broken up. This form of arsenic will remain for many hours in the stomach without material modification so that the substance may be identified directly. In one case of criminal poisoning, the defence set up the theory that the dead person had been taking homœopathic triturations of arsenic, but the expert for the state

pointed out that the arsenic found in the stomach was distinctly crystalline, which proved that it had not been triturated. The prisoner was convicted and executed, and subsequently his attorney admitted the correctness of the inference, and the remainder of the arsenic, which had been bought for the poisoning, was given to the expert.

By making thin sections of fossils and coal much information may be obtained as to the origin of these materials. Coal shows vivid evidence of its vegetable origin, not only by the impressions of leaves and stems, that are visible to the naked eye, but on

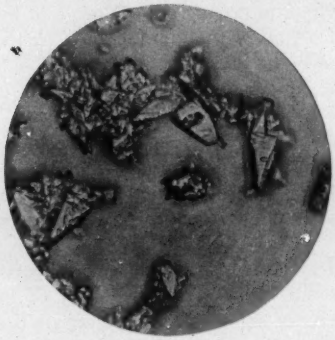
Section of coal × 120. Showing vegetable cells.

magnification, the minute details of the cell structure and spores. Considerable advance has been made lately in the study of coal, by treatment with hydrofluoric acid, by which the mineral matter is in great part removed, and thus the remains of the vegetable structures made more evident.

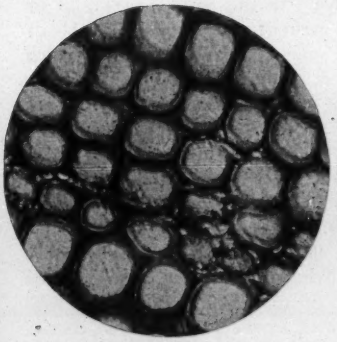
The fossil tree-trunks in the petrified forests of Arizona have retained the vegetable structure through the silicification, even to very minute detail, and by the microscope it can be shown that they are cone-bearers, related to our pines and spruces. They show clearly the peculiar dotted cells, technically known as the "bordered pits" which are characteristic of that group of plants.

In the field of pathology and bacteriology the microscope has been of immense use. Its applicability has been materially increased by the use of cultures and staining systems. The inven-

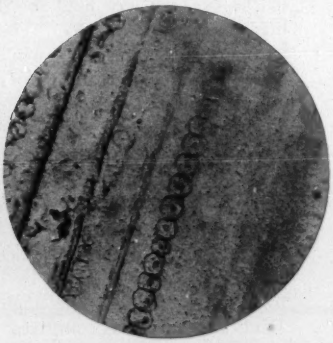
tion of the solid culture medium, by Doctor Koch, has been one of the most important accessories in this work. Microörganisms can be cultivated in many liquids and on many surfaces, but the



Crystal of milk sugar × 100.



Tranverse section of petrified wood. Petrified Forest of Arizona × 120.



Section of petrified wood × 120. Showing "bordered pits" which indicate cone-bearing tree.

different species remain in intimate mixture and study of individual forms is impossible. By incorporating into the culture fluid a substance which is liquid when moderately warm, but solid at ordinary temperatures, the organisms can be cultivated separately. Gelatin and agar are usually employed, the latter being especially

applicable for cultures made at blood heat, as its jelly does not melt at that temperature. The procedure, in outline, is to prepare a sterile culture medium containing the jelly-forming substance, inoculate under proper precautions, spread it in a shallow dish, and cover it with a protecting lid. When cold the jelly sets, and the individual organisms multiply in their places, soon forming colonies so numerous that they are large enough to be seen by the naked eye. In growing, some organisms produce marked changes in the condition of the gelatin or agar. Some digest it partly, causing spots of liquid, others produce colors. One well-known and common organism produces a blood-red stain. From the colonies thus indicated, portions can be taken and separately cultivated, just as one can gather seeds from the mature plants of a garden.

Another great advance was made when the methods of staining bacteria and tissues were invented. Many of the coal-tar dyes have the property of adhering firmly to certain tissues and organisms, while other tissues and organisms, which show no difference to the eye, will not hold the dye. In this way objects may be made much more distinct. The germ of tuberculosis is capable of taking certain dyes firmly, while some associated organisms which closely resemble it in form will not retain these colors. By dyeing the material and then subjecting it to treatment with dilute acid, all organisms but the tubercle germ will lose their color, so that a marked contrast is obtained.

One of the latest applications of the microscope is its use in determining the index of refraction. This datum is the expression of the amount to which the ray of light is bent on passing from air into the mass of the substance under examination. The figure for the index is obtained by dividing the sine of the angle of incidence by that of the angle of refraction. In dealing with solids and liquids as compared with air the quotient is, of course, always greater than unity. Differentiation of both solid and liquid substances can be made rapidly and accurately by determinations of this index. In microscopic work, the method is largely applied in examining crystals.

In examining substances more or less transparent immersed in a liquid, the individual particles are seen to be surrounded by a series of bands either in monotone or in colors. The relative

extent of these bands depends on the difference between the refractive index of the substance and that of the liquid bathing it. If the objects examined are entirely homogeneous, without color, have the same refractive and dispersive powers, and also the same absorptive powers for light as the liquid, they will become invisible. All these conditions as coincident are not found in practice, so there is always some visibility. In practice the vanishing of the dark bands is the phenomenon that is used to aid in the examination. If, for instance, a crystal is examined successively in liquids of which the index of refraction is known, it is possible to determine that of the solid, by noting the liquid in which the dark bands are just eliminated.

By these means crystals of very small size can be identified and many interesting and valuable results have already been obtained. Dr. Edgar T. Wherry, of the United States Bureau of Chemistry, has for several years been devoting a great deal of attention to this phase of research and has made many determinations. One of the most interesting and valuable was in the detecting of the cause of mortality among bees in some parts of Pennsylvania. The honey on being examined was found to contain crystals of unusual form, and as the amount was very small resort was had to the determination of the index of refraction, by which the substance was identified as melezitose, a sugar that is of no nutritive value to the bee. This had been obtained probably by the bees collecting exudations on pine trees, during a period in which flowers were scarce. Doctor Wherry made also examinations of some high explosives which were of different colors as produced in different factories and found that the difference was due to enclosures in the crystals.

Efforts have been made of late to apply the refractive index to the differentiation of the common alkaloids. Some of these are powerful poisons, and as they are used in small amount the processes of analysis have to be very delicate. Many of the tests depend upon color produced by reagents, but in these the alkaloid is destroyed. The crystalline forms of the alkaloid itself or of its salts are sometimes fairly characteristic, but as a rule such method is only applicable to the pure substance. In toxicologic analysis the material is often difficult to obtain perfectly pure, and this complicates the work. Naturally the determination of the refrac-

tive index seems to be a possible method, but one difficulty has arisen, namely, to secure liquids which do not have a solvent action on the crystal. It is obvious that if the substance dissolves in the liquid bathing it, no accurate test can be made. Human ingenuity is, however, almost limitless, and it is reasonable to expect that some method will be found by which this useful datum will be made available for the toxicologist and pharmacologist in identifying these important substances.

British Developments in Nitrogen Fixation.—The *Chemical News* presents the following abstract of a report from the Ministry of Munitions. The synthetic ammonia factory at Billingham, designed to manufacture about 60,000 tons of ammonium nitrate annually for war purposes, was commenced by the Ministry of Munitions early in 1918, but at the time of the Armistice was only very little advanced. It has since been taken over from the Government by Messrs. Brunner, Mond and Company, Ltd., and is being re-designed to manufacture peace products, chiefly fertilizers. The subsidiary company they have promoted, Synthetic Ammonia and Nitrates, Ltd., will have a capital of £5,000,000, is at present concentrating upon designs for an initial plant to produce 25 tons of ammonia per day, or about 6000 to 7000 tons of nitrogen annually. Their works are, however, being laid out so that this small nucleus installation may be quickly enlarged to 100 tons per day and afterward to a maximum capacity of 300 tons per day, or about 80,000 tons of nitrogen annually. The original Government site of 260 acres is being increased to about 1000 acres in all, and two ship berths on the River Tees have been acquired. This increased accommodation has been found necessary in order to give ample room for the development of the whole scheme, which includes the manufacture of a number of by-products. There is also to be an oxidation plant of a capacity of 10,000 to 12,000 tons of nitric acid annually. A British company, Cumberland Coal Power and Chemicals, Ltd., has also been formed to erect works in England to operate the Claude process for the manufacture of synthetic ammonia. Information to hand states that a full-sized commercial ammonia unit, working at 1000 atmospheres, is now running satisfactorily in France, producing at the rate of 5 tons of ammonia per day. The British Cyanides Company is continuing at Birmingham its large-scale experiments on fixation of nitrogen by the barium process, employing fuel-heated furnaces. Though these experiments have been partially successful, final conclusions as to the ultimate possibilities of the process have not yet been reached. The works erected at Dagenham by the Nitrogen Products Company to manufacture ammonium nitrate during the war period from cyanamide by the Ostwald process are now closed. H. L.

ELECTROLYTIC CONCENTRATION OF AQUEOUS SOLUTIONS OF NITRIC ACID. I.*

BY

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THE nitric acid produced in the arc processes for the fixation of atmospheric nitrogen [1] usually has a concentration of 33 to 35 per cent. A dilute acid is also produced in its formation by the oxidation of ammonia,[2] while in the ordinary method of manufacture from Chili saltpetre a dilute acid (38° Bè. or less) is obtained from the final towers or tourilles of the condensing system. On account of the many uses for concentrated nitric acid, the problem of concentrating its dilute aqueous solutions is an important one and one which has received much attention. As is well known, dilute aqueous solutions of nitric acid can only be concentrated to about 68 per cent. HNO_3 by distillation at atmospheric pressure, due to the formation of a mixture of maximum boiling point; and by distillation with concentrated sulphuric acid aqueous solutions containing 68 per cent. nitric acid (mixture of maximum boiling point) can be concentrated to over 90 per cent.[3] Attempts have been made to concentrate dilute nitric acid electrolytically,[4] but, as Molinari points out,[5] these have not yielded practical results.

When an aqueous solution of nitric acid is electrolyzed between platinum electrodes, the NO_3-ions and the H-ions migrate, respectively, to the anode and the cathode and are there discharged, the resulting NO_3-radicals reacting with the water of the solution in accordance with the equation:

$$2NO_3 + H_2O = 2HNO_3 + O.$$

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* Communicated by Professor Creighton.

[1] Creighton, H. J. M., This Journal, 187, 379–399 (1919).

[2] Creighton, H. J. M., *Ibid.*, 187, 705–714 (1919).

[3] Cf. Creighton, H. J. M., and J. H. Githens, *ibid.*, 179, 161 (1915); Creighton, H. J. M., and H. G. Smith, *ibid.*, 180, 703 (1915).

[4] German Patent, No. 180,052; English Patent, No. 18,603 of 1906.

[5] "General and Industrial Chemistry (Inorganic)," p. 396, second edition. P. Blakiston's Son and Co., Philadelphia, 1920.

This oxygen and the hydrogen set free at the cathode escape from the electrolyte in the proportions in which they are present in water. The net result of electrolysis is, therefore, the decomposition of some of the water and a consequent increase in the concentration of the nitric acid which remains in the solution. If, however, the dilute nitric acid is electrolyzed in a cell which is divided into an anodic and cathodic section by means of a porous diaphragm and F faradays of electricity are passed through the electrolyte, the following changes occur: At the cathode F gram-ions of hydrogen discharge and escape from the solution, but, since the transport number of the NO_3-ion in nitric acid is *ca.* 0.15, this loss is partially compensated by migration into the cathodic section of 0.85 F gram-ions of hydrogen from the anodic section of the cell. At the same time 0.15 F gram-ions of NO_3 pass from the cathodic to the anodic section. There occurs, therefore, during the passage of the current, a loss of 0.15 F gram-molecules of nitric acid in the cathodic section. At the anode F gram-ions of NO_3 discharge. The nitrate radicals which result do not leave the solution, but react with the water to form F gram-ions of hydrogen, F gram-ions of NO_3 and 0.5 F gram-atoms of oxygen, the latter escaping from the electrolyte. Since the anodic section gains F gram-ions of hydrogen through the NO_3-ion discharge and 0.15 F gram-ions of NO_3 by migration from the cathodic section, and loses 0.85 F gram-ions of hydrogen by migration to the cathodic section, there results a gain of 0.15 F gram-molecules of nitric acid in the anolyte. Thus, the concentration of the acid in the anolyte is increased at the expense of that in the catholyte, the gain in the former being equal to the loss in the latter.

Some of the hydrogen set free in the nascent state at the cathode reduces part of the nitric acid in the vicinity of the electrode, say through the stages:

$$HNO_3 \longrightarrow NO_2 \longrightarrow HNO_2 \longrightarrow NO \longrightarrow H_2N.OH \longrightarrow NH_3.$$

The nature of the reduction product formed depends on the temperature, current-density, concentration of the acid and the material of the cathode. As early as 1839 Schönbein [6] observed that nitric acid was reduced at the cathode when the acid was concentrated, and that current-density played a rôle, while later Brester [7]

[6] *Pogg. Ann.*, 47, 563 (1839).
[7] *Archiv. de Genève* (N. S.), 28, 60 (1866).

found that during the electrolysis of dilute nitric acid ammonia was formed at the cathode. More recently, Ihle [8] has shown that, for a given concentration of nitric acid, ammonia and hydroxylamine are formed at a smooth platinum cathode when the current-density is above a definite value, and that this value increases with the concentration of the acid. Thus, at different acid concentrations the minimum current-density at which ammonia is formed is:

Concentration of nitric acid..	14.67	28.73	43.34	85.37 per cent.
Current-density	0.15	1.122	5.64	860.0 amp/dm.^{2}

In studying the influence of the material of the cathode on the nature of the reduction product, Tafel [9] has found that while nitric acid (in the presence of 50 per cent. sulphuric acid) is reduced only to hydroxylamine at a mercury or well-amalgamated cathode, it is reduced at a copper cathode to ammonia; with a lead cathode 40 per cent. of the nitric acid is reduced to hydroxylamine, and with a platinum cathode there is no reduction when the acid is very dilute. Electrolysis of 40 per cent. nitric acid containing a small quantity of oxides of nitrogen has been found to yield pure nitric oxide at a carbon, graphite, gold or platinum cathode.[10]

It is evident from the foregoing that during electrolysis in a diaphragm cell not only will the concentration of the nitric acid in the catholyte be decreased by loss of hydrogen and migration of NO_3-ions to the anolyte, but also by partial conversion of the acid to the oxides of nitrogen (which escape from the solution), ammonia, etc. If, however, electrolysis is carried out under such conditions that the acid is reduced to the oxides of nitrogen, loss of the acid by reduction may be overcome, partially at least, by leading the gases formed in the cathode section into the anolyte where, in the presence of water and nascent oxygen, the oxides of nitrogen are converted to nitric acid, thus further concentrating the acid in the anodic section of the cell.

Some years ago the writer carried out a few experiments on concentrating aqueous solutions of nitric acid by electrolytic means. This work was unavoidably interrupted but has recently been resumed. In this paper a brief account of the results of these preliminary experiments is given.

A few experiments were first carried out in which 70–71 per

[8] *Z. physik. Chem.*, 19, 572 (1895).
[9] *Z. anorg. Chem.*, 31, 289 (1902).
[10] Meister, Lucius and Brüning, English Patent, No. 10,522 of 1911.

cent. nitric acid was electrolyzed in a cell without a diaphragm between the following electrodes: (1) A carbon anode and cathode, (2) a smooth platinum anode and a lead cathode, and (3) a smooth platinum anode and a carbon cathode. With the first combination of electrodes it was found that with an anodic current-density of 4–5 amp./dm.^{2} fragments of the anode began to break off with a loud cracking sound within a few seconds after the current had been turned on. In one instance a large piece of the anode was shot off with such violence that it cracked the glass beaker containing the electrolyte. After electrolysis had proceeded for a short time the anode had disintegrated to such an extent as to render it useless.[11] The cathode did not undergo this disintegration. It was found on repeating the electrolysis with the second combination of electrodes, using a cathodic current-density of 5–8 amp./dm.^{2}, that the cathode gradually lost its brightness and malleability and was transformed into a soft, powdery, allotropic modification of lead.[12] Accordingly, in the concentration experiments which follow platinum electrodes were employed, although a carbon cathode could have been used with a platinum anode.

The electrolysis cell used for the concentration experiments consisted of a glass cylinder in which was placed a porous, unglazed, porcelain cylinder closed at the bottom. The former contained the anolyte and the latter the catholyte. The top of the porous cylinder was closed by a stopper through which passed the cathode. A glass tube also passed through this stopper and carried the nitrous gases and hydrogen evolved in the cathodic section into the anolyte immediately below the anode. The stopper contained a third opening through which electrolyte could be removed or introduced. The acid used for the anolyte and catholyte was *c. p.* nitric acid (sp. g. = 1.42) containing about 71 per cent. HNO_3. The electrolyses were carried out in an open room in winter weather at a temperature of from 5 to 10° C. The increase in the concentration of nitric acid in the anolyte (or the decrease in concentration in the catholyte) was followed by removing 10 cc. of the electrolyte, diluting to 1000 cc. and neutralizing 10 cc. of this dilute solution with a standard solution of barium hydroxide.

[11] This phenomenon of the disintegration of carbon anodes in nitric acid is being studied further.

[12] Creighton, H. J. M., *Jour. Amer. Chem. Soc.*, 37, 2064 (1915).

In all experiments the final concentration of the acid was determined by analyzing a known weight of the anolyte.

In Table I are given the results of a concentration experiment

TABLE I.

Time Hours	Current-strength Amperes	Potential difference Volts	Quantity of electricity consumed Amp.-hrs.	Energy Consumed Kw.-hrs.	Concentration of HNO_3 in Anolyte %	Concentration of HNO_3 in Catholyte %
0	6	3.5	0	0	71.70	71.70
2	6	3.5	12	0.042	74.35	....
4	6	3.5	24	0.084	76.44	....
6	6	3.5	36	0.126	78.88	....
8	6	3.5	48	0.168	81.35	....
11*	6	3.5	66	0.231	84.00	50.36
11	2	2.0	66	0.231	84.00	50.36
22	2	2.0	88	0.275	....	....
22	6	3.5	88	0.275	....	....
25	6	3.5	106	0.338	88.40	....
27	6	3.5	118	0.380	92.22	....
34	6	3.5	160	0.507	94.40	14.04

*The color of the catholyte was blue-green.

TABLE II.

Time Hours	Current-strength Amperes	Potential difference Volts	Quantity of electricity consumed Amp.-hrs.	Energy consumed Kw.-hrs.	Concentration of HNO_3 in anolyte %
0	7	3.4	0	0	71.4
4	7	3.4	28	0.0952	73.5
8	7	3.4	56	0.1904	76.7
12	7	3.4	84	0.2856	77.2
21*	7	3.4	147	0.4998	80.6
25	7	3.4	175	0.5950	83.0
29	7	3.4	203	0.6902	84.5
29	6	3.0	203	0.6902	84.5
35†	6	3.0	239	0.7982	...
46	6	3.0	305	0.9962	90.1
46	8	4.0	305	0.9962	90.1
48	8	4.5	321	1.0642	...
49	8	5.5	329	1.1042	...
50	8	6.0	337	1.1502	...
51	8	6.5	345	1.2002	92.2

*250 cc. catholyte removed and 250 cc. 71.4% HNO_3 added to cathode section.
†200 cc. catholyte removed and 200 cc. 71.4% HNO_3 added to cathodic section.

in which the volumes of anolyte and catholyte used were, respectively, 250 cc. and 150 cc. of 71.7 per cent. nitric acid. In a second experiment, the results of which are recorded in Table II,

the volume of anolyte was 975 cc. (1385 grams) and the volume of catholyte was 550 cc. (780 grams). In this experiment 345 ampere-hours of current were passed through the cell and the concentration of the anolyte raised from 71.4 to 92.2 per cent. HNO_3 ($d\,^{15°}_{4°} = 1.4987$). The weight of the anolyte at the end of the experiment was 1210 grams. That this weight was not greater was due to losses by evaporation, to the removal during the experiment of 150 cc. for titration, and probably to loss by diffusion into the cathodic section. In another experiment an attempt was made to increase further the concentration of the 92.2 per cent. acid obtained in the preceding experiment. Three hundred grams of the 92.2 per cent. acid were placed in the anodic section and 285 grams of 71.4 per cent. acid were placed in the cathodic section of a small concentrating cell. As it was desired to obtain as pure an acid as possible, the nitrous gases formed in the cathodic section were not led into the anolyte and the temperature of the electrolyte was not allowed to rise above 8° C. The acid was electrolyzed for seven hours, during which time 48 ampere-hours of current were passed through the cell and 0.300 kw.-hr. of energy consumed. At the conclusion of electrolysis there were 350 grams of anolyte containing 99.65 per cent. HNO_3 ($d\,^{15°}_{4°} = 1.5193$). On being removed from the cell at the conclusion of electrolysis this acid was almost colorless; but after standing for twenty-four hours in a room at ordinary temperature it became lemon yellow in color.

In each of the foregoing experiments the porous cylinder underwent considerable disintegration and could not be used for a second experiment. This difficulty can probably be overcome, however, by using an aluminum cylinder, since it has been found that a cylinder of this material undergoes but little change in weight on being immersed in 70 per cent. nitric acid for six weeks.

In order to determine to what extent "spent acid" (*i.e.*, a mixture of nitric and sulphuric acids diluted and partially deprived of the former acid by use in nitrating organic substances, *e.g.*, glycerine) could be concentrated electrolytically, a spent acid containing 70.03 per cent. H_2SO_4, 10.06 per cent. HNO_3 and 19.91 per cent. H_2O was electrolyzed, the gases evolved in the cathodic section of the electrolysis cell being led into the anolyte immediately below the anode. Four hundred and fifty-five grams of the spent acid were placed in the anodic section of the cell and 370 grams in

the cathodic section. The acid was electrolyzed for ten hours with a current of eight amperes, the mean potential difference being 6.75 volts. At the conclusion of electrolysis the weight of anolyte was 440 grams. The anolyte was analyzed and found to contain 74.4 per cent. H_2SO_4, 21.32 per cent. HNO_3 and 4.28 per cent. H_2O.

SUMMARY.

1. A number of preliminary experiments on concentrating aqueous solutions of nitric acid by electrolytic means have been carried out.

2. The concentration of nitric acid has been increased from 71 to over 99 per cent. HNO_3 by electrolysis in a diaphragm cell.

3. The concentrations of nitric and sulphuric acids in "spent acid" have been materially increased and the amount of water decreased by electrolysis.

DEPARTMENT OF CHEMISTRY,
SWARTHMORE COLLEGE,
SWARTHMORE, PENNA.,
December 10, 1921.

An Acoustical Galvanometer for the Measurement of Small Alternating Currents. F. R. WATSON and L. B. HAM. (*Phys. Rev.*, September, 1921.)—Ordinarily the word galvanometer calls up the image of a moving part actuated by the action of one magnetic field upon another. In the acoustical galvanometer there is one magnetic field, because there is a current of electricity, but there is not a second one. The alternating current to be measured passes through a Western Electric No. 417W loud-speaking telephone receiver. The plate of this is set in vibration and sound waves are produced in an enclosed mass of air. This closed chamber consists of two cylinders joined by a tube. The receiver forms the end of one cylinder and the other is closed by a plate of glass. Within this double resonator standing waves are formed. In the connecting tube is suspended by a quartz thread a Rayleigh disc, a microscope cover glass in fact, with its plane at an angle to the axis of the tube. When standing waves develop this disc turns through an angle. A ray of light enters through the glass end, is reflected from the suspended disc and is received upon a scale. When the disc turns this reflected ray is deviated. When the sound wave had a frequency of 510 vibrations per sec., 5.7×10^{-8} amperes produced a deflection of one mm. on a scale one metre distant from the deflected disc. The sensitivity varies with the frequency.

The suggestion is made that the instrument can be made to measure larger alternating currents. It may be used to replace the ear in telephone research and in psychological work where an objective measure is to be correlated with subjective impressions through the ear.

G. F. S.

The Distinction Between Intrinsic and Spurious Contact E. M. F. S. and the Question of the Absorption of Radiation by Metals in Quanta. R. A. MILLIKAN. (*Phys. Rev.*, Sept., 1921.)—The wide-reaching conclusions so clearly presented by Richardson in his Vice-presidential address at the 1921 B. A. A. S. to the effect that the data of the photo-electric effect demonstrate the existence of a real contact difference of potential are still further buttressed by this present paper which summarizes a long series of researches. "The accompanying experiments, then, taken in connection with those of Page and those of Kadesch and Hennings, show in the most beautiful quantitative way that all clean metals possess intrinsic contact e. m. f. s." "Thus the century-old dispute as to the reality of intrinsic contact e. m. f. s. appears to be quite definitely settled by experiments of this type." "It it to emphasize, too, that the result is a purely experimental one which is quite independent of any theory, although it is beautifully in accord with the theory of electron atmospheres."

G. F. S.

Some New Experiments on Gravitation. CHARLES F. BRUSH. (*Phys. Rev.*, August, 1921.)—At the meeting of the American Physical Society in April, 1921, the results of certain experiments in relation to gravitation were presented, as follows:

"1. Gravitational Attractions of a Kg. each of Bismuth and of Zinc for a Small Nearby Ball of Silver Are Not the Same.

"2. A Gravity Pendulum with a Bismuth Bob Has a Shorter Period than a Similar Pendulum of Exactly the Same Oscillation Length Having a Zinc Bob.

"3. A Torsion Pendulum Having Equal Horizontal Arms Loaded with Equal Weights of Bismuth Has a Shorter Period than when the Arms Are Loaded with Equal Weights of Zinc of the Same Weight as the Bismuth Loads; The Radii of Gyration Being Exactly the Same in Both Cases."

These conclusions are in direct opposition to the accepted relation of mass to weight and are in contradiction to the results of careful experiments made by others. Should they, upon repetition, prove to be justified they will render necessary a vast amount of scientific reconstruction.

G. F. S.

PRINTING TELEGRAPH BY RADIO.*

BY

R. A. HEISING, E.E., M.S.

Research Laboratory, American Telephone and Telegraph Company and the Western Electric Company, Inc.

In the *Annales des Postes, Telegraphes et Telephones* for June, 1921, M. M. Henri Abraham and Rene Planiol describe their experiments with a printing telegraph operated by radio, and mention the fact that similar experiments had been made in the United States. The tests in this country were made during the latter part of 1919 by engineers of the American Telephone and Telegraph Company and the Western Electric Company, Inc., between New York City and Cliffwood, New Jersey. The work was mainly the adaptation of present-day radio to the commercial multiplex printing telegraph,[1] or in other words, the substitution of a radio transmission link for the customary wire transmission line.

In these experiments a radio transmitter was installed at the Western Electric Company's building at 463 West Street, and a receiver at their experimental station at Cliffwood, New Jersey, a distance of twenty-five miles. The printing telegraph, both transmitting and recording ends, was located in the printing telegraph laboratory in the same building as the radio transmitter, but separate from it. The usual outgoing signals from the printer were transmitted by wire to the radio room, where, by means of a relay controlling the radio transmitter, they were converted into radio signals. The received signals at Cliffwood actuated a polar relay and converted the radio signals back to wire signals which were relayed by wire back to the printer laboratory in New York. The transmitting and printing of the telegraphic messages were thus done in the same room but with a combined radio and wire transmission circuit between.

RADIO TRANSMITTER.

The radio transmitter used in these experiments was of the audion class. It contained six tubes of the type known as fifty-watt tubes. One was used in an oscillator circuit to maintain the

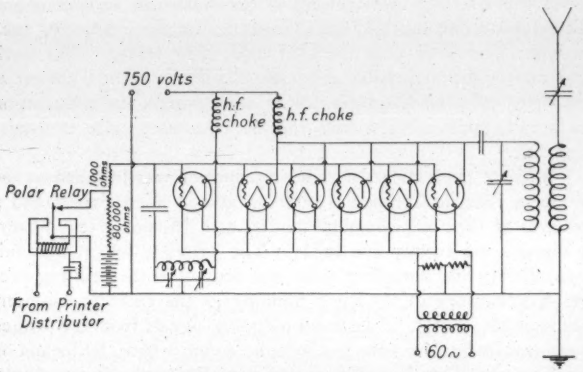
* Communicated by Col. John J. Carty, D.Eng., Associate Editor.

[1] *Electrical World*, April 3, 1915.

frequency constant and the other five were in parallel as amplifiers. The amplifier tubes delivered their power directly into the antenna. A plate potential of 750 volts was used and three amperes at 450 metres was secured in the antenna.

The control of the transmitter was by means of a Rainey polar relay. This relay operated on the grid circuit of the tubes, applying a negative potential to stop oscillations and removing it to start them. The signals from the printing distributor are in the form of positive and negative pulses. The relay controlled the radio transmitter in such a manner that the positive impulses put

FIG. 1.



Printing telegraph transmitter.

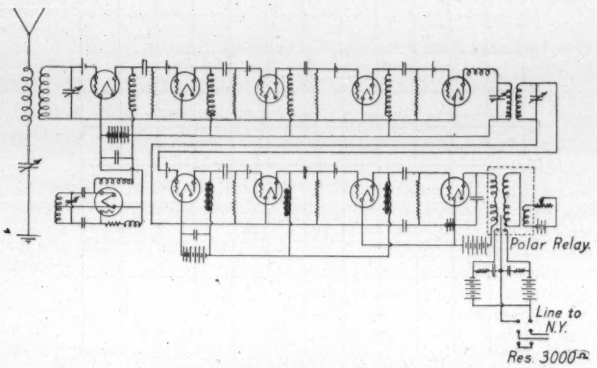
sustained power into the antenna and the negative impulses removed it. The radio transmitter and control circuits are shown in Fig. 1.

RADIO RECEIVER.

The receiving circuit with repeating relay is shown in Fig. 2. To eliminate interference, a highly selective circuit was necessary. The principal interference in the neighborhood of New York on such waves as 450 metres is not static or strays, but spark stations. Static and strays at times are bad, but the interference from spark stations is quite continuous and was at first a source of trouble. The sharpness of the receiving circuit as finally constructed was such that very few errors in transmission could be attributed to

interference. A curve indicating the high selectivity is shown in Fig. 3. The strength of the received signal at Cliffwood was such that connecting a detector directly to the antenna gave about one microampere rectified plate current. Sufficient amplification was used to give a maximum of 20 mil-amperes through the relay. Since the relay could be adjusted to give satisfactory operation with two mil-amperes, the 20 mil-amperes secured gave excellent operation.

FIG. 2.



Radio receiving set for printing telegraph.

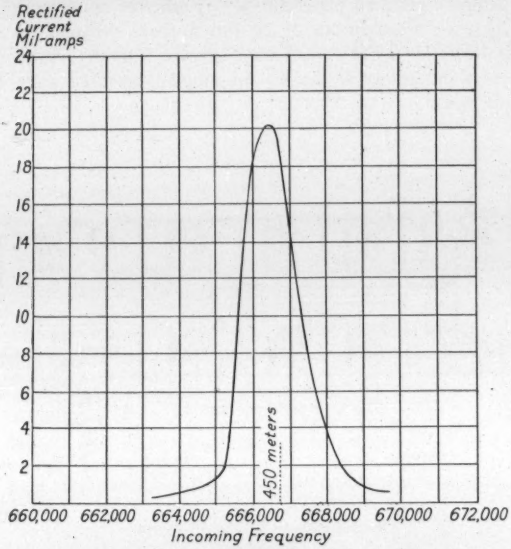
RESULTS.

Fig. 4 shows an oscillogram of the behavior during the first operation on November 20th. This represents a test signal being sent at the rate of forty-five words (270 characters) per minute per channel. The upper curve is that of the signal arriving in the radio room from the printer sending distributor. It is in the form of positive and negative impulses. The middle curve is rectified antenna current at the radio transmitter to show the character of the conversion into a radio signal. The bottom curve is the signal received back from Cliffwood by wire. A slight lag is observed in this signal. It is caused partly by the receiving set relay but largely by the receiving set radio circuit.

The printer was operated first on November 20, 1919. No trouble was encountered in keeping the mechanism synchronized as the signals from around the circuit were much better than those

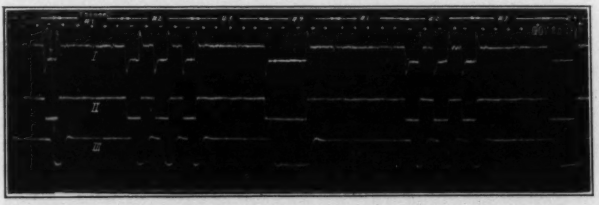
from many wire circuits. On November 25th two channels of the four were operated for about an hour, 29,000 characters were

FIG. 3.



Resonance curve of printing telegraph receiving set, Cliffwood, N. J.

FIG. 4.



transmitted with fourteen possible radio mistakes. This latter figure is thought to be too large because the errors due to wearing of the tape from continual use numbered thirty-five. The four-

teen errors were those which could not be conclusively attributed to the condition of the tape.

The speed with which the printer could be operated was in no way limited by the radio. The speed used in the tests—180 words per minute, or 10,800 words per hour on all four channels together—happened to be the rate at which other experimental work in the printer laboratory was being done. The oscillograms showed a character of signal that indicated that the printer could have been operated at its highest rated speed of 12,720 words per hour without trouble.

The short line or start-stop printer has also been operated over this circuit. It is worked with less difficulty due to the increased length of the signal impulses.

These tests were witnessed by a number of persons. They have been repeated on several occasions since with similar success.

Protecting Merchant Ships from Submarines.—The menace of the submarine was made evident during the war by many a loss and by much sacrifice of life. The British fleet cleared the sea of German and Austrian cruisers almost entirely, but for a long while the submarine continued its work. The problem of preventing future action is a question of great importance, and efforts have been made at the Washington conference to secure some declaration limiting the use of these insidious enemies of ocean travel. In a paper before the North-East Coast Institution of Engineers and Ship-Builders, Sir E. H. T. D'Eyncourt details some of the expedients employed or suggested for overcoming the submarine warfare that Germany conducted, especially against British commerce. It is known that at one time the sinkings were very frequent, and the total loss of British merchant vessels and their cargoes was enormous. Many suggestions were made, of course, a large proportion of which were by persons who had no practical knowledge of conditions and were, therefore, not heeded. Some plans were not carried out because of the time required for the construction. One of the plans that was tried to a limited extent, and which seems to have been efficient, was to construct an outside shell on each side of the ship. This was called a "bulge." It was not considered profitable to attach it to small ships, but with large ones it was practicable. A ship so protected was attacked by a submarine in the Mediterranean in June, 1917. The torpedo hit the bulge full amidships; the opposite compartment was flooded to right the vessel, which returned to port and was quickly repaired. One striking feature was that the original thin hull of the ship was not damaged. Later in 1917, and in 1918, ships thus protected were hit and escaped.

The experience of the war showed that speed is a material pro-

tection against submarines. Very few fast vessels were seriously injured. It seems that if these two methods, bulge protection and high speed, could have been applied early in the war, the results of the German submarine campaign would have been much less serious to the allies.

The British authorities did not take kindly to the proposition to build the protected ships, nor to the building of large wheat-carriers, plans for which were sketched by the engineers.

The following is a brief statement of the protected vessel, the type being a cargo carrier and tanker:

Length, overall	500	feet.
Length, between perpendiculars	480	feet.
Breadth, extreme over bulges	72	feet.
Depth to upper deck	34	feet.
Draught	27	feet.
Corresponding displacement	20,000	tons.
Deadweight	15,000	tons.
I.H.P. of twin screw machinery	6,000	tons.
Maximum speed	13½	knots.

The design provided for the vessel to be protected for a length of about 300 feet amidships (*i.e.*, 60 per cent. of the total length) by bulge protection of such width that the hull proper would be about 11 feet (on the average) from the seat of a possible underwater explosion. The bulge would be divided by a longitudinal bulkhead into two compartments, the outer one being empty and the inner one containing water (on outward voyages) or oil (on homeward voyages). The vessel could then carry a large addition to her cargo of oil on homeward voyages.

The profile of the vessel was arranged to be practically symmetrical about amidships so that the "double-ended" appearance thereby obtained would render attack by submarine difficult.

H. L.

Tuolumne River and Canyon. (*U. S. Geological Survey Press Bulletin, No. 481.*)—Tuolumne River rises in a group of glacial lakes on or near the Sierra divide in California. The river flows through beautiful upland meadows in its upper part and then through a canyon, nearly 80 miles long, which it has cut in solid granite. For a distance of about 25 miles, according to the Geological Survey, the upper part of this canyon is 3000 to 4000 feet deep and is known as the Grand Canyon of the Tuolumne. At the lower end of this canyon lies Hetch Hetchy Valley, which is smaller than the Yosemite Valley but resembles it very much in every other way. The river finally passes through its lower canyon into the San Joaquin Valley.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

COLOR SENSITIVE PHOTOGRAPHIC PLATES AND METHODS OF SENSITIZING BY BATHING.[1]

By F. M. Walters, Jr., and Raymond Davis.

[ABSTRACT.]

ORDINARY plates which are sensitive to the blue, violet and ultra-violet may be made sensitive to other colors by the use of certain dyes. These may be incorporated in the emulsion, or the dry plates may be made sensitive by bathing in dilute solutions of the dyes.

This investigation was undertaken to study some of the conditions to be observed in the use of certain dyes for making ordinary plates color sensitive by bathing.

Pinacyanol (a red sensitizer) gives good results in dilute alcoholic solutions when used with ammonia, but plates bathed in water and stock solution keep much better and are almost as sensitive, provided they are thoroughly washed before sentitizing. This is because the soluble salts contained in the emulsion prevent the sensitizing action by flocculating the dye.

Wash or soak the plate in water for five minutes, and bathe for two minutes in the following bath at 18° C.

Water	100 parts
Pinacyanol (stock solution 1 to 1000)	4 "

Rinse the plate in ethyl alcohol for three or four minutes and dry as rapidly as possible.

Stock solutions consist of 1 part dye to 1000 parts ethyl alcohol.

Films are best sensitized in a bath containing water, alcohol, ammonia and stock solution as follows. Bathe for four minutes in

Water	65 parts
Ethyl alcohol 95 per cent.	35 "
Pinacyanol (stock solution 1 to 1000)	4 "
Ammonia 28 per cent.	2 "

Rinse in alcohol for three or four minutes and dry rapidly.

Dicyanin (used to sensitize for infra-red light) gives a much

* Communicated by the Director.

[1] Scientific Paper No. 422.

greater sensitiveness and extends farther into the infra-red when used in a dilute alcoholic solution with ammonia than when used with water alone.

Water	65 parts
Ethyl alcohol 95 per cent.	35 "
Dicyanin (stock solution 1 to 1000)	4 "
Ammonia 28 per cent.	4 "

Rinse in alcohol for three or four minutes and dry rapidly.

The modern orthochromatic (green, yellow, and orange) sensitizers, pinachrome, pinaverdol, orthochrome T, and homocol are much less sensitive to the action of soluble salts contained in the emulsion than are pinacyanol and dicyanin. Ammonia may be added to a sensitizing bath of water and stock solution, but does not increase the sensitizing action appreciably except in the case of homocol.

Certain brands of orthochromatic plates were found to be superior to plates bathed with erythrosin (Kahlbaum's) but no commercial panchromatic plate compared favorably with pinacyanol bathed plates.

It was found that washing commercial panchromatic plates had a favorable action on the color sensitiveness. While the effect of water is not so marked as that of dilute ammonia, the increase in fog which accompanies the use of ammonia is largely avoided.

Five minutes' washing or soaking in water is sufficient. The plates should be dried rapidly, an alcohol rinse will assist materially.

OPERATION OF THE MODULATOR TUBE IN RADIO TELEPHONE SETS.[2]

By E. S. Purington.

[ABSTRACT.]

IN radio telephone transmitter circuits using electron tubes the radiated power is caused to vary at speech frequencies usually by one of the three following methods: First, by variable absorption of the output power of a radio generator, as by a microphone in the antenna circuit; or second, by varying at speech frequencies the operating grid voltage of a radio generator, as in grid modulation; or third, by varying at speech frequencies the input plate voltage of a radio generator, as in plate modulation. The third method

[2] Scientific Paper No. 423.

is used in practically all commercial and military types of apparatus. It is superior to the others with respect to the intensity of signal conveyed for a given total input power, and with respect to inherent reliability and tone quality. This paper deals with phenomena in transmitters of this third type.

Three orders of current occur in the transmitter networks—direct, audio or speech frequency, and radio frequency. For convenience the network may be analysed into four parts—the direct power supply, the modulator unit, the generator unit, the radiator unit. The modulator receives direct power from the supply unit, produces speech frequency power which it delivers together with direct power to the generator unit. The generator in consequence produces modulated radio frequency power, which it delivers to the radiator. Devices are included in the generator unit to prevent radio power working back into the modulator, and similarly in the modulator to prevent speech power working back to the direct power supply.

Important curves for the generator are obtained by determining how the output radio current and how the input plate current depended upon the input plate voltage. The first indicates the modulated wave form which results from any specified speech variation in the input voltage. The second indicates the essential nature of the load which the generator imposes upon the modulator unit. The curves usually approximate straight lines, with however a falling off from linearity at high voltages. The plate current-plate voltage characteristic over any range of operation defines a resistance R_b which symbolizes the useful resistance load imposed upon the modulator. The modulator unit then consists of a tube and its load in parallel, the two being supplied from the direct power source through a common line impedance, an audio-frequency choke coil. The modulator tube operates as a periodic amplifier of speech currents, the output corresponding to the voltage impressed on its grid by the speech transformer.

The load on a tube acting as an amplifier or a generator may be expressed in terms of wave forms of plate voltage and plate space currents. For each frequency present, the numerical value of the load impedance is the ratio of the alternating voltage to the alternating space current, and the phase angle of the load is given by the departure from exact phase opposition. For a phase angle numerically exceeding ninety electrical degrees, the tube is a con-

sumer rather than a producer of power. Three kinds of phenomena prevent the true load impedance upon the modulator tube being derivable from the characteristics of the generator unit, as symbolized by the resistance R_b. First, the audio choke coil is of finite impedance resulting in an inductive component to the total load. Such an effect is not serious provided the choke coil impedance is two or three times the resistance R_b. Second, the audio impedance of condensers and inductances, especially those which operate as valves to prevent flow of radio energy into the modulator, may cause disturbing effects upon the load. Third, a distortion of wave forms corresponding to a capacity load results from the necessity of the generator producing power not only to overcome resistance losses, but also to vary the electromagnetic energy associated with the radiator circuit.

The value of a radio telephone transmitter as a conveyor of signals is measured not by the power it can deliver to the radiator, but rather by the variations of power during speech. Since the variations of output power depend upon the power of the modulator tubes, it is desirable to use modulators sufficiently powerful to modulate up to the point of distortion. Usually optimum results are obtained when the total power rating of the modulators equals the power rating of the oscillators. Under these conditions, the load impedance on the modulators due to the characteristics of the generator unit becomes one into which the modulators are capable of operating with high electrical efficiency.

RECOMMENDED SPECIFICATION FOR WATER RESISTING SPAR VARNISH.[3]

THIS specification was prepared under the auspices of the Bureau of Standards by the U. S. Interdepartmental Committee on Paint Specification Standardization, September 12, 1921. The committee consisted of representatives of the War, Navy, Agriculture, Interior, Post Office, Treasury, and Commerce Departments, the Panama Canal, the U. S. Shipping Board, and the Educational Bureau of the Paint Manufacturers' Association of the United States. The revision is largely based upon criticism of the first edition made by certain varnish manufacturers' clubs.

[3] Circular No. 103, 2nd edition.

The committee's draft was submitted to numerous representatives of the varnish industry, and careful consideration was given to their suggestions.

The specification gives the general requirements and detailed methods of sampling and testing, as well as basis of purchase. The general requirements are:

The varnish shall be suitable for use on both outside and inside surfaces of vessels, buildings, etc., and must be resistant to air, light and water. The manufacturer is given wide latitude in the selection of raw materials and processes of manufacture, so that he may produce a varnish of the highest quality. It must meet the following requirements:

Appearance.—Clear and transparent.

Color.—Not darker than a solution of 3 g. of potassium dichromate in 100 c.c. of pure sulphuric acid, specific gravity 1.84.

Flash Point (closed cup).—Not below 30° C. (85° F.).

Non-volatile Matter.—Not less than 40 per cent. by weight.

Set by Touch.—In not more than 5 hours.

Dry Hard and Tough.—In not more than 24 hours.

Working Properties.—Varnish must have good brushing, flowing, covering, and leveling properties.

Safety of Working.—Varnish must pass the draft test.

Water Resistance.—Dried film must withstand cold water for 18 hours and boiling water for 15 minutes without whitening or dulling.

Toughness.—Varnish must pass a 50 per cent. Kauri reduction test at 24° C. (75° F.).

RECOMMENDED SPECIFICATION FOR INTERIOR VARNISH.[1]

THIS specification was prepared under the auspices of the Bureau of Standards by the U. S. Interdepartmental Committee on Paint Specification Standardization, September 12, 1921. The committee consisted of representatives of the War, Navy, Agriculture, Interior, Post Office, Treasury and Commerce Departments, the Panama Canal, the U. S. Shipping Board, and the Educational Bureau of the Paint Manufacturers' Association of the United States. The committee's draft was submitted to numerous repre-

[1] Circular No. 117.

sentatives of the varnish industry, and careful consideration was given to their suggestions.

The specifications give the general requirements and detailed methods of sampling and testing, as well as basis of purchase. The general requirements are:

The varnish shall be suitable for general interior use, including both rubbed and unrubbed finish, exclusive of floors. It must be capable of easy application with a brush in the ordinary manner according to the rules of good standard practice, must flow out to a good level coat free from runs, sags, pits, or other defects, and dry with reasonable promptness to a hard, somewhat elastic glossy coating which can be rubbed in 48 hours or less. The manufacturer is given wide latitude in the selection of raw materials and processes of manufacture, so that he may produce a varnish of the highest quality. The varnish must meet the following requirements:

Appearance.—Clear and transparent.

Color.—Not darker than a solution of 3 g. of potassium dichromate in 100 c.c. of pure sulphuric acid, specific gravity 1.84.

Flash Point (closed cup).—Not below 30° C. (85° F.).

Non-volatile Matter.—Not less than 45 per cent. by weight.

Set to Touch.—In not more than 4 hours.

Dry Hard.—In not more than 24 hours.

Toughness.—Film on metal must stand rapid bending over a rod 3 mm. (⅛ inch) in diameter.

Working Properties.—Must have good brushing, flowing, covering, leveling, and rubbing properties; and must show no impairment of lustre or other defect when used where natural or illuminating gases are burned or when subjected to air currents during the process of drying or application.

Water Resistance.—The dried film must stand application of cold water for not less than 18 hours without whitening or showing other visible defect.

NOTES FROM THE RESEARCH LABORATORY EASTMAN KODAK COMPANY.*

A METHOD OF PRODUCING REVERSED DYE IMAGES.[1]

By J. I. Crabtree.

REVERSED dye images may be obtained on motion picture film or any other suitable support by first dyeing the film with a dye that is capable of being reduced to a leuco base, and after tinting, bleaching in an ordinary acid hypo-bath, washing, and then removing the silver image by using a solvent of silver such as Farmer's reducer. Two methods of procedure are described: The first method making use of a single bath containing the dye as well as the bleaching agent, and the second, dyeing or tinting the gelatin-silver image in one bath and then bleaching it in a separate bath. In both cases the film is subsequently washed and then immersed in the reducing solution.

The success of the process is largely dependent on the careful adjustment of the time of bleaching. Thorough washing before the film is placed in the reducing bath is of importance, otherwise the leuco base is mordanted to the silver ferrocyanide image and on prolonged washing is oxidized to the dye. The result is the production of a positive dye image. This difficulty, along with several others, is mentioned, and suggestions are given for avoiding them. Several interesting effects may be obtained by slight variations of the procedure as: (1) Production of a toned silver image with the highlights tinted by substituting for the last reducing bath either a uranium-toning bath or a dye-toning bath; (2) line effects by increasing the time of bleaching and then toning as in (1); (3) unusual tinted effects by merely dyeing and bleaching and washing with slight increase of the bleaching time. The theory of the process is as follows: The dye (such as methylene blue) in the presence of hypo is locally reduced to the leuco base in the region of the silver image, and on washing, the leuco base is

* Communicated by the Director.

[1] Communication No. 97 from the Research Laboratory, Eastman Kodak Company, and published in *B. J. Phot.*, Jan. 2, 1921, p. 32; *Photo. Era*, Jan., 1921, p. 10.

washed out more rapidly than the dye, leaving a reversed dye image with silver in the highlights. Removal of the silver from the highlights then leaves the desired reversed dye image. (An interesting criticism of the article appears in the editorial column of the *B. J.*, 1921, p. 46.)

A Method for the Micro-analysis of Gases by the Use of the Pirani Pressure Gauge. RESEARCH STAFF OF THE GENERAL ELECTRIC COMPANY, London. (*Proc. Phys. Soc. London,* August 15, 1921.)—The method is applicable to gases at pressures of .1 to .001 mm. mercury, and is based upon a study of the pressures which are found as the temperature is raised. For each substance present there is a temperature at which a large change in the vapor pressure takes place. Below this "condensation temperature" there is practically no pressure due to the substance.

Let a mixture of vapors at low pressure be taken for analysis. Then a tube containing a single vapor should be prepared for each of the vapors that may be present. The mixture and the several tubes are raised in temperature after having been in a liquid air bath and the different pressures are measured. At some temperature there will appear a sudden increase in the pressure exerted by the mixture. Thereupon the pressures of the several tubes are examined. It may be that more than one will show a notable increase above its pressure at the low initial temperature. In that case the one with the highest condensation temperature is recognized as a constituent of the mixture. The raising of the temperature is then continued until again a rapid increase in pressure manifests itself, when a second constituent is identified, and so on.

For such a method there must be a means of measuring vapor-pressures with accuracy up to .1 mm. The Pirani gauge in a modified form was found to be suitable. A tungsten filament was joined in a bridge with three resistances having negligible temperature coefficients. The filament was placed in the space where the pressure was to be measured. As the pressure of the surrounding gas changed the resistance of the filament changed, owing to escape of heat at a different rate. The difference of potential applied to the bridge was adjusted so as to restore the original resistance of the filament. From the new applied P. D. the pressure can be read off from a calibration curve. It is claimed that this type of gauge has advantages in comparison with the McLeod instrument, though not in point of speed.

"This method is extraordinarily sensitive and certain. One per cent. of water in CO_2 may be detected—an unfavorable case because the main constituent evaporates before the impurity." After the constituents are known their amounts may be rapidly estimated.

G. F. S.

NOTES FROM NELA RESEARCH LABORATORIES.*

DECAY OF BIOLUMINESCENCE IN CYPRIDINA.

By William R. Amberson.

THE decay of luminescence in the Japanese ostracod, *Cypridina hilgendorfii,* Müller, has been studied by a photographic method. The light reaction in this animal is known to consist in the oxidation of a substrate, luciferin, catalyzed by an enzyme, luciferase. The former is obtained free from enzyme in aqueous solution by extraction of the dried and powdered animals with boiling water. Enzyme solutions are similarly obtained by cold water extraction.

Direct photometric study is not feasible, since (1) the decay is very rapid, and (2) it is often necessary to study two solutions simultaneously. Such simultaneous study of several solutions, to determine the effect of changes in concentration of enzyme or substrate, in oxygen tension, and so on, is made necessary by the fact that in aqueous solution luciferin oxidizes spontaneously even when no enzyme is present, and will not keep for successive measurements. All attempts at standardization of solutions have failed, but by dilution and simultaneous study of two portions of the same solution accurate relative values can be obtained.

Moving photographic records of the progress of the reaction are taken on negative motion picture film. Films are mounted and revolved on a kymograph. Solutions to be studied are placed in one-inch test tubes, blackened externally with the exception of a small vertical slit window 1.5 mm. wide, cut in a phosphor-bronze strip and applied to one side of the tube. This window is brought to a distance of one millimetre from the film. Two such tubes are arranged to give records running side by side upon one strip of film, and covering two-thirds of the film width. Measured luciferin solutions, of any desired concentrations, are placed in the tubes, and measured quantities of enzyme are added suddenly from pipettes at the proper moment. Films are moved past the windows at rates of from 4 to 10 mm. per second.

Calibration is achieved through the use of Cypridina light itself. Films upon which moving records have been impressed are

* Communicated by the Director.

clamped in a holder between two metal strips bent in the arc of a circle with a 15 centimetre radius. The inner strip carries a row of fifteen small round windows, in which photographic film filters of known transmissions are placed. This row of openings comes opposite to the unexposed third of the film. Filter transmission values range from 5 per cent. to 100 per cent. Illumination for calibration is secured from a test tube of Cypridina solution placed at the centre of the circle. During exposure this solution is stirred rapidly by motor, to insure complete mixing of enzyme and luciferin, as well as homogeneous radial distribution of the light. Fifteen calibration densities, corresponding to known relative intensity values are thus obtained upon development. Calibration exposures are for one minute. The films are then developed.

Photographic densities of both calibration and moving records are read by the optical pyrometer. Under the conditions of the experiment the two sets of values are comparable. A curve of blackening is drawn for each experiment, and the densities from the moving records are referred to it for the evaluation of intensities along the curves.

The following results are indicated:

(1) The decay curve for Cypridina luminescence assumes the form of a bimolecular reaction in which two reactants are present in equimolecular concentrations. The basic assumption in the work is that the light intensity, I, at any instant is a measure of the reaction velocity at that instant. Upon this assumption the experimental values are expressed by the usual equation, in which A is the initial concentration of reacting material and x the decrease in that concentration in the time t.

$$I = \frac{dx}{dt} = k(A - x)^2$$

This may be expressed in the straight line form,

$$\frac{1}{\sqrt{I}} = a + bt.$$

Where a

$$a = \frac{1}{A\sqrt{k}} \quad \text{and} \quad b = \sqrt{k}$$

The experimental values are normally plotted in this form, since I and not $(A\text{-}x)$ is directly measured by the method. It has been a frequent practice among students of inorganic phosphorescence to plot their results in this form. The theory in such cases

has assumed the recombination of positive and negative ions, present in equal numbers in the phosphorescent material after separation by the action of previously incident radiation. There is therefore at least a superficial resemblance between the decay curves of inorganic phosphorescence and the curve for Cypridina. The nature of the two reactants in the Cypridina luminescence is not yet clear.

(2) With concentrated enzyme solutions the velocity of reaction is proportional to the concentration of the enzyme. This relationship has frequently been noted in other enzyme reactions.

Further studies are being made upon the relation of oxygen to the reaction, the temperature coefficient, the effect of luciferin concentration, and similar problems.

VISIBILITY CURVES FOR COLOR DEFECTIVES.

By Margaret C. Shields.

[ABSTRACT.]

THIS paper aims to determine just what deviations from the normal spectral luminosity curve are to be found in cases of partial color-blindness. The apparatus used is a Lummer-Brodhun spectro-photometer which has been in use at this laboratory for some time, and the method of determining the luminosity curve consists essentially in a photometric comparison of adjacent parts of the spectrum, so close together that the color difference in each photometric determination is, at the most, small enough to be negligible as a disturbing factor. Both the instrument and the method have been previously described.[1] The results were reduced to an energy basis.

The writer (a deuteranope) finds her own visibility maximum displaced from the normal (556–557$\mu\mu$) to 571$\mu\mu$. This is in accord with previous results in so far as they are specific on the point. Although previous work has shown different maxima in the visibility curve for different individuals,[2] the attempt has only occasionally been made to correlate these with the various types of color-defect. In one such case, a deuteranope reported

[1] *Astrophysical Journal*, vol. 35, p. 237; and vol. 48, p. 65.

[2] Watson, *Proc. Roy. Soc.*, vol. 88, p. 404; Tufts, *Phys. Rev.*, vol. 25, p. 433; Coblentz, *Bull. Bur. St.*, vol. 14, p. 167.

by Coblentz, the maximum of the visibility curve was shifted to 578$\mu\mu$. According to the results of Abney, interpreted on the basis of the three-process theory of color vision, the maximum should be at 590$\mu\mu$.

The three-process theory, just referred to, would seem to require that the total luminosity for a person lacking the green sense should be about 0.7 of normal; and for a red-blind person about 0.3. The writer's conclusion is that such a relation does not exist. For a light source at 2045° K., her own (deuteranope) curve and that of an unusually red-sensitive normal show just about the same deviation of maximum from that of the average normal, when all curves are plotted to equal area. No reason is apparent for reducing one of these curves more than the other. Plotting them to equal areas does not give an unduly high maximum in the red. The same is true of Coblentz's four cases with maxima in the red, but fails for the one with the maximum in the green.

A further attempt was made to answer the question as to the integral visibility, for the normal and for the color-blind, by making measurements of the absolute threshold throughout the spectrum. For the author, for the red-sensitive subject before mentioned, and for a normal, the thresholds lie, in the red end of the spectrum, in the order corresponding to the ordinates of the respective visibility curves, but this is not true in the green and blue.

The author's conclusions are (1) that an abnormal visibility function is not necessarily associated with color defect; (2) that color defect, on the other hand, *does* condition a definite modification of the visibility function. A theory of vision should interrelate brightness sense and color sense to account for this. (3) It still seems doubtful that color defect involves a lowered brightness sense such as would appear to be the inevitable consequence of the Young-Helmholtz theory.

NOTES FROM THE LABORATORY OF PURE SCIENCE, NELA RESEARCH LABORATORIES.*

ACCURACY IN COLOR-MATCHING.

By W. E. Forsythe.

THE color-temperature of an incandescent source has been defined as the temperature at which it is necessary to operate a black body so that the color of the integral light from the black body is the same as that from the source being studied. Since the light from all radiating substances cannot be accurately matched in color with that of a black body at a particular temperature, it is more accurate to define the color-temperature as that temperature of a black body at which the ratio of the radiant flux at some two arbitrarily chosen wave-lengths is the same as that for the radiating substance being investigated.

In general color-temperature measurements can be quite accurately made with an ordinary Lummer-Brodhun contrast photometer. The process of determining such temperatures is known as color-matching.

Two tests have been made of the accuracy of color-matching with an ordinary Lummer-Brodhun contrast photometer.

In the first test, several observers made color-matches using two tungsten lamps so set that there was an illumination of 5.1 foot-candles on the photometer screen. It was found that experienced observers agreed in their setting to an accuracy of about 3°K., while inexperienced observers differed by only about 5°K.

There was also a test made to see if there was any difference in the accuracy depending upon the illumination on the photometer screen. Tests were made by several observers for illumination varying from 1.8 to 45 foot-candles. There were no very definite differences in accuracy found for the different illuminations.

A lamp was very carefully color-matched with the color standard maintained by this Laboratory and sent to the Bureau of Standards to be compared with their standard of color. The aver-

* Communicated by the Director.

age of the value obtained before it was sent to the Bureau of Standards and the value obtained after it was returned was 3087°K. The value found by the Bureau of Standards was 3085°K. Later a lamp was sent to this Laboratory from the Bureau of Standards and compared with the standard of this Laboratory. The values found by the two laboratories agree exactly, the value being 2848°K.

The above tests indicate the accuracy that may be obtained in such work both in making the color-matches and in determining the color-temperature scale in different laboratories.

NELA RESEARCH LABORATORIES,
CLEVELAND, OHIO,
November 16, 1921.

Two Forms of Isotopes.—In a communication to the *Chemical News* of October 28th, last, Prof. Bohuslay Brauner, of Prague, presents in some detail a study of the question of isotopy in connection with the international revision of atomic weights. Some chemists have expressed the view that the exact determination of these weights and the statement of them to several places of decimals have lost a good deal of importance. The atomic weights of an element may represent only that of the average mixture of its isotopes. Professor Brauner points out that at present two classes of isotopes are known. One class consists of radioactive elements, products of the same or different series of radioactive disintegration (Soddy's isotopes), the other class (isotopes of J. J. Thomson and Aston) represents mixtures of extremely similar elements, which were formerly regarded as individual elements respectively. To this class belong the chlorine isotopes obtained by Harkins.

The first class of isotopes descends from uranium or thorium and the different series end in "leads" of the atomic weights 206 and 208, but all such representing one place do not necessarily occur together. Those of the second class, so far as now known, always occur in association, in the same proportion, the mixture having always the same average combining weight. Aston has shown that separation can be affected by electromagnetic analysis, and that their atomic masses are represented by integers on the base O = 16. They run to-day from hydrogen to caesium. Incidental to these considerations, a modification of Mendeléef's law is necessary in regard to the isotopes, but it may still stand with reference to the pure elements. As a conclusion from his studies, Brauner recommends that the term "atomic masses" be used only for whole numbers of the isotopes of the second class, while the term "atomic weights" should be applied to the numbers obtained by chemical methods and the use of the balance, no distinction being made between pure elements, mixtures of isotopes or single isotopes. H. L.

NOTES FROM THE U. S. BUREAU OF CHEMISTRY.*

THE EFFECT OF SOME DECOLORIZING CARBONS UPON THE COLOR AND COLLOIDS OF CANE SUGAR.[1]

By Joseph F. Brewster and William G. Raines, Jr.

[ABSTRACT.]

SUGAR cane juice in 3000-pound lots was clarified by sulphur-lime treatment and by kieselguhr-decolorizing-carbon filtration. In general, more colloidal matter is removed by treatment with kieselguhr alone than with sulphur dioxide and lime. The sulphur dioxide and lime treatment removes very little, if any, coloring matter, while the various carbons used showed different decolorizing power and different ability to remove colloids. The amount of total colloidal material present appears to affect the decolorization by carbons.

THE EFFECT OF VARYING HYDROGEN ION CONCENTRATION UPON THE DECOLORIZATION OF CANE JUICE WITH CARBON.[2]

By Joseph F. Brewster and William G. Raines, Jr.

[ABSTRACT.]

COMPARATIVE decolorization of sugar cane juice at varying hydrogen ion concentrations was determined by adjusting the reaction of the juice by the addition of acid or alkali, treating with decolorizing carbon, boiling, and filtering. The color remaining in the samples was then read with the aid of the Hess-Ives tint photometer and the color units obtained. Determinations were made at p_H values ranging from 8 to 4. In general, best decolorization is obtained at $p_H = 4$. At this acidity, however, inversion is rapid, and it is doubtful whether much advantage is to be gained in practice by working at such acidity. It would be necessary to maintain careful control.

* Communicated by the Acting Chief of the Bureau.

[1] Published in *J. Ind. Eng. Chem.* (1921), 13: 921.

[2] Published in *J. Ind. Eng. Chem.* (1921), 13: 1043.

THE ODOROUS CONSTITUENTS OF PEACHES.[1]

By Frederick B. Power and Victor K. Chesnut.

[ABSTRACT.]

No information on the nature of the substances to which the odor of the peach is due appears to have been recorded in chemical literature. Although many preparations designated as "peach oil" or "peach essence" have long been in use for flavoring purposes, they consist for the most part of purely empirical mixtures of esters and essential oils with other more specific aromatic substances.

In the present investigation only the fresh pulp of ripe Georgia Belle peaches was employed, and the pits were carefully excluded.

The results of the investigation and the conclusions therefrom may be summarized as follows:

1. The odorous constituents of the peach may be said to consist chiefly of the linalyl esters of formic, acetic, valeric, and caprylic acids, together with a considerable proportion of acetaldehyde and a very small amount of an aldehyde of higher molecular weight. It is probable that the volatile acids are present to some extent in a free state.

2. A minute amount of acetaldehyde is contained in the emanation from the entire ripe fruit.

3. No trace of hydrocyanic acid or benzaldehyde could be detected in the distillate from peach pulp. It may therefore be concluded that the occurrence of the glucoside amygdalin is restricted to the kernels of the fruit, and that no other compound capable of yielding hydrocyanic acid is present in the pulp.

4. By extracting a concentrated distillate of the peach with ether, a very small quantity of an essential oil was obtained. This was a pale yellow, limpid liquid, which possessed an exceedingly fragrant and intense peach-like odor. When cooled somewhat below the ordinary temperature, it formed a concrete, transparent mass, interspersed with minute, acicular crystals. These crystals evidently consisted of a paraffin hydrocarbon, which, when indirectly isolated, melted at about 52°. The yield of essential oil was 0.00074 per cent. of the weight of pulp employed.

In addition to the esters mentioned, the peach oil contained a little acetaldehyde and furfural, the latter having doubtless been

[1] Published in *J. Am. Chem. Soc.* (1921), **43**: 1725.

produced during the process of distillation by the action of organic acids on the sugar contained in the fruit. The presence of cadinene, or a compound giving a similar color reaction, was also indicated.

The essential oil of peach is a very unstable product. When kept for a comparatively short time in a glass tube with a capillary constriction and only occasionally exposed to the air, it became converted into a black, viscid mass, and had then completely lost its original fragrance. This change is in accordance with the character of the constituents of the oil as determined by the present investigation. If the oil, as first obtained, be brought into a glass tube, and hermetically sealed, it appears to be capable of preservation for an indefinite period.

Astronomy at the Antipodes. The *New Zealand Journal of Science and Technology* gives an account of offers recently made by Yale University of apparatus for use in a New Zealand Observatory, in order to make systematic studies of the southern sky. New Zealand is about as far south of the equator as New Haven is north, the fortieth parallel of south latitude passing through it. The offer was made through Dr. Frank Schlesinger, Director of the Yale Observatory, who since 1915 has been constantly interested in the matter. Funds having been made available, it is now possible to make the following offers to the New Zealanders. To provide a telescope with six-inch aperture, mounting driving clock and plate-glass photographic plates. This is to be used in photographing the southern sky, and when such work has been accomplished, outfit is to be returned to Yale, unless provision is made for further use in New Zealand.

To provide a large photographing telescope, the optical parts of which will cost about $25,000. The complete instrument will be worth about $100,000. With this Yale will send two astronomers to undertake urgently required observations on southern stars. These observers will use the outfit about half the time, the other half being available for local workers. The outfit will be left in place, if a satisfactory site can be secured, and New Zealand prepared to assist in providing land, buildings, foundations, offices and residences for the staff.

These offers are considered very liberal, and it is claimed by members of the New Zealand Astronomical Society that their territory offers the best opportunities for the examination of the southern sky by modern methods.

H. L.

Thermal Conductivity and Diffusivity of Concrete. (A. P. CARMAN and R. A. NELSON, Bulletin 122, Engineering Experiment Station, University of Illinois.)—As a result of the rapidly increasing use of concrete in various forms of construction it has become important to have some definite information as to the thermal conductivity and diffusivity of different concrete mixtures.

During the last ten years the composition and methods of preparation of concrete mixtures have been studied and standardized, and present investigators have had the advantage of dealing with concrete mixtures which can be described much more definitely than was possible a few years ago. The results of only a few determinations of the thermal conductivity of concrete have been published previously, and to a large extent these lack definiteness in regard to the composition and method of preparation of the material.

Attempts to Detact the Presence of Neutrons in a Discharge Tube. J. L. GLASSON. (*Phil. Mag.*, Oct., 1921.)—Last year Sir Ernest Rutherford suggested the existence of a substance having zero electric charge on its nucleus. Such a nucleus might come into existence if an ordinary hydrogen atom were to meet some experience that would make its solitary electron fall into the positive nucleus. Since the positive charge of the nucleus equals the negative charge of the electron the resultant neutron would have no residual charge.

Search was made for the hypothetical neutron in the place where there was a chance of finding it, that is among the positive rays of a hydrogen discharge tube where free hydrogen nuclei and electrons abound. No evidence of its existence was discovered. Should subsequent investigation detect this elusive particle, it will facilitate the labors of those who seek to learn the structure of nuclei.

G. F. S.

On the Spectra of Lead Isotopes. T. R. MERTON. (*Proc. Royal Soc.*, A 702.)—About a year ago this investigator showed that the strongest line in the arc spectrum of lead of length 4058 angstrom units has slightly different wave-lengths when lead specimens of different ancestry are used. The measured wave-length got with lead from pitchblende exceeded that given by ordinary lead by .005 of a unit, while the length from ordinary lead in turn was greater than that obtained by the use of the metal derived from thorite by .002 unit. Owing to the possession of a considerable quantity of lead derived from Australian Carnotite it has become possible to extend the investigation to four lines altogether. In every case it has been found that the wave-length of the Carnotite lead is greater than that of ordinary lead. For the line cited above the difference amounts to .011 unit. Thus the isotopes are winning a secure place in good physical society.

G. F. S.

NOTES FROM THE U. S. BUREAU OF MINES.*

PRESENT STATUS OF COAL CARBONIZATION AT LOW TEMPERATURES.

By Joseph D. Davis.

For the past twenty years an enormous amount of experimental work has been done in this country and in Europe on the carbonization of coal at low temperatures. Most of this work has been carried out on a laboratory scale, or at least on a semi-commercial scale, and only recently have results been obtained that can be used directly by the carbonization engineer. One object in view in the experimental work has been to learn from a purely scientific standpoint more of the composition of coal and its thermal decomposition. Another object has been the discovery and commercial development of more economical methods for processing fuels than the well-known high-temperature methods.

The problem of coal constitution and thermal decomposition is a long way from solution, although considerable progress has been made. Of the chemical constitution of coal, little is known as yet, but the yield of distillation products obtained under fixed temperature conditions, as well as their general nature, has been empirically worked out; the actual chemical reactions involved, however, have not been fully explained.

The technical application of low-temperature carbonization is still in its infancy and development has been slow, mainly for three reasons: (1) adequate fundamental knowledge of coal constitution and thermal decomposition is lacking; (2) evolution of suitable retorting apparatus is slow, owing to the low-heat conductivity of coal and the consequent difficulty of designing retorts which have appreciable capacity and also the requisite low-temperature gradients; (3) a market for the rather special distillation products, however valuable they may prove to be in the future, does not exist and must be created. Also, in order that a low-temperature industry may be firmly established, it is necessary that the popular prejudice against soft coke be overcome, and it will take time to accomplish this.

* Communicated by the Director.

It does not appear that low-temperature methods are destined soon to occupy an important place in the gas industry in so far as gas for city supply is concerned. They may, however, be used to advantage in the production of industrial gas. Details as to low-temperature methods and the amount and character of products obtained are presented in a recent paper published by the Bureau, which was presented before the meeting of the American Gas Association at Chicago on November 9, 1921.

ROCK DRILLING TESTS IN THE TRI-STATE MINING DISTRICT.

By C. R. Forbes.

DURING the past few years the questions of rock drills, drill bits and drill steel have received much attention, and many improvements have been brought about, both in the design and in the use of rock drills and drilling equipment. Among these improvements the use of smaller changes in gage between the different steels has been one of the most important. With the old types of piston drill, gage changes of ¼ inch or more were often used, necessitating the use of steel of from 3 to 3½ inches in diameter to start when deep holes were to be drilled. As the work of drilling varies almost directly with the quantity of material removed, the use of these large sizes of steel resulted in a great loss of time and energy. At the present time, many companies are successfully using gage changes of $^1/_{16}$ inch, and in some cases changes of only $^1/_{32}$ inch are used. Although these very small changes require great care and accuracy on the part of the drill sharpener, both in forging and gaging the steels and in proper heat treatment, still the cost of this extra work in the drill shop is more than offset by the increased efficiency of the drilling machines. Another improvement in drilling practice that has been brought about recently by several companies is the use of 1-inch steel in place of 1¼ inch in the large mounted hammer drills. The advantage of the smaller cross-section consists in the saving in steel, faster drilling speed, and saving in labor on the part of the miner in handling the lighter steel.

In order to find out whether or not these improvements were applicable in the Missouri-Kansas-Oklahoma districts, the Mississippi Valley experiment station of the Bureau of Mines, work-

ing in cooperation with the Missouri School of Mines and Metallurgy, conducted a series of experiments extending over a period of four months, beginning May 1, 1921. The tests were made by I. F. and J. H. Hodges, senior students from the Missouri School of Mines and Metallurgy, who had had considerable practical experience as miners. The work was done in the Bluebird mine of the O. M. Bilharz Mining Company, near Commerce, Oklahoma, and was under the immediate supervision of F. H. Gartung, superintendent for that company.

The conclusions from the tests are as follows: (1) One-eighth-inch gage change and 24-inch changes in steel lengths are best for conditions in this district when using 1¼-inch steel; (2) one-inch steel can be used successfully, with the large hammer drills for drilling holes up to ten feet in depth, at a considerable saving in time and energy on the part of the miner. Gage changes of $^1/_{16}$ inch and changes in steel lengths of 24 inches can be used with the one-inch steel. The tests are described more fully in a recent paper issued by the Bureau. Further work along this line is being conducted by the mines.

BENTONITE.

By Raymond B. Ladoo.

THE name bentonite has been applied to a group or series of clay-like materials characterized by an alkaline oxide and alkaline earth content of 5 to 10 per cent., fine grain size, high-absorptive powers, and usually very strong colloidal properties. It varies considerably in composition and physical properties. It is often light yellow, but may be cream to black. It is exceedingly fine grained, very plastic and highly absorbent; when wetted it will absorb more than three times its weight or seven times its volume of water. Some varieties when wetted with water expand to more than six times (some experimenters report eight times) their original volume. The wetted material is exceedingly smooth and soft and feels like soft soap. Unlike most clays, bentonite is easily fusible at a comparatively low temperature.

Some varieties when finely ground and thoroughly agitated with water will stay in suspension indefinitely, forming a translucent gelatinous mass. The addition of small amounts of acids or sodium chloride seems to have little or no tendency to aid coagula-

tion or settling. Other varieties go into suspension more easily, but settle out again.

Some, and perhaps all, of the minerals of the bentonite group have the property of allowing easy replacement of the alkaline and earth oxides, one with another. This property has been utilized for the softening of certain types of hard water.

It has been mined in Wyoming, California, South Dakota, and occurs also in Montana, Arizona, Utah, Texas, Tennessee, Idaho, New Mexico, and British Columbia.

It has been used principally in the manufacture of antiphlogistine, dressing for horses' hoofs, retarder in plaster, filler in paper and soap, as an adulterant in drugs and candy. In recent years its unusual properties have attracted considerable attention, and research work has been undertaken to study this material and to develop the best methods for its utilization, especially by the Forest Products Laboratory of the Department of Agriculture, Madison, Wisconsin, in paper making and de-inking news print. Other uses suggested are as a filler for rubber, phonograph records, textiles, cordage, electrical insulation and leather; in the manufacture of paint and adhesive paste; for de-watering crude petroleum; as a base for massage creams, printer's inks, and precipitating lake colors. Further details are given in a paper recently issued by the Bureau.

Studies on Cooling of Fresh Concrete in Freezing Weather. (TOKUJIRO YOSHIDA, Bulletin 123, Engineering Experiment Station, University of Illinois.)—The practice of placing concrete in freezing weather renders important a knowledge of the rate at which this material will cool, and the effect of the various methods of protecting the freshly placed concrete from the cold.

This bulletin deals with certain experimental work carried on at the Experiment Station with the object of obtaining data on the length of time required for concrete of a given temperature to lose its heat and become cold enough to freeze when it is exposed to temperature lower than the freezing point of water. Some experiments were made on the protective effect of coverings.

While it is probable that these experiments do not give complete data regarding concreting in freezing weather under all possible conditions, it is considered that they throw some light on the behavior of fresh concrete at low temperatures, and indicate the necessity of protection or other precautions.

THE FRANKLIN INSTITUTE.

(Proceedings of the Stated Meeting held Wednesday, December 21, 1921.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, December 21, 1921.

MR. ALFRED W. GIBBS, *Chairman pro tem.*

Additions to membership, since last report, 9.

Reports of progress were presented by the Committee on Library and the Committee on Science and the Arts.

The following nominations were made for officers and managers to be voted for at the annual election to be held on January 18, 1922:

For President (to serve one year) Walton Clark.

For Vice-President (to serve three years) Henry Howson.

For Treasurer (to serve one year) Benjamin Franklin.

For Managers (to serve three years) Francis T. Chambers, W. C. L. Eglin, Alfred C. Harrison, Nathan Hayward, Charles A. Hexamer, Robert W. Lesley, Marshall S. Morgan, E. H. Sanborn.

For Managers (to serve two years) Clarence A. Hall, Haseltine Smith.

The paper of the evening on "The Application of the Fundamental Knowledge of Portland Cement to Its Manufacture and Use" was presented by P. H. Bates, A.B., B.S., Chief, Structural and Miscellaneous Materials Division, Bureau of Standards, Washington, D. C.

The results of various attempts to determine the mineral constituents of Portland cement, culminating in the successful attempt of Rankin, were reviewed. The work of the Bureau of Standards in determining the physical properties of the different constituents was described. The relative amounts of these occurring in cement of normal manufacture, and the possibility and economy of producing, in the process of manufacture, the determined amount of any constituent were discussed. The quality of cements of relatively the the same composition but different constitution, the desirability of more refined methods of testing to determine the qualities not revealed by present tests and the need of cements of different qualities for different uses were also considered. The subject was illustrated by lantern slides. After a brief discussion, a unanimous vote of thanks was extended to the speaker.

Adjourned.

R. B. OWENS,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, December 7, 1921.)

HALL OF THE INSTITUTE,
PHILADELPHIA, December 7, 1921.

DR. H. J. M. CREIGHTON *in the Chair.*

The following report was presented for final action:

No. 2761: Greaves-Etchells Electric Arc Furnace. The Certificate of Merit to Messrs. H. A. Greaves and Harry Etchells, of Sheffield, England.

The following report was presented for first reading:

No. 2781 and No. 2782 } The Franklin Medal.

R. B. OWENS,
Secretary.

SECTIONS.

Section of Physics and Chemistry.—A meeting of the Section was held in the Hall of the Institute on Thursday evening, November 10th, at eight o'clock, with Dr. Thomas D. Cope in the Chair. The minutes of the previous meeting were approved as read.

Albert W. Hull, Ph.D., of the Research Laboratory of the General Electric Company, Schenectady, New York, delivered an address on "The Crystal Structures of the Common Elements." A description was given of the apparatus for the analysis of crystals by means of the X-rays. The available data on this subject were reviewed and summarized. The lecture was illustrated with lantern slides. The paper was discussed; a vote of thanks was extended to Doctor Hull; and the meeting adjourned.

JOSEPH S. HEPBURN,
Secretary.

Section of Physics and Chemistry.—A meeting of the Section was held in the Hall of the Institute on Thursday evening, December 1, 1921, at 8 o'clock. Dr. Harry F. Keller in the Chair. The minutes of the previous meeting were read and approved.

Eugene T. Allen, Ph.D., Reseach Chemist, Geophysical Laboratory of the Carnegie Institution, Washington, D. C., presented a communication entitled, "Chemical Aspects of Volcanism," in which the origin of volcanic gases and the factors influencing their chemical composition were discussed. The address was illustrated with lantern slides.

The paper was discussed by Mr. Fulweiler, Doctors Ehrenfeld and Allen, and others. On motion of Dr. George A. Hoadley, a vote of thanks was tendered Doctor Allen.

The meeting then adjourned.

JOSEPH S. HEPBURN,
Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, December 14, 1921.)

RESIDENT.

MR. FRANCIS J. CHESTERMAN, The Bell Telephone Company of Pennsylvania, Philadelphia, Pennsylvania.

DR. FREDERICK EHRENFELD, University of Pennsylvania, Philadelphia, Pennsylvania.

MR. J. M. HAMMOND, 1429 N. 21st Street, Philadelphia, Pennsylvania.

MR. JOSEPH A. MARTOCELLO, 229 N. Thirteenth Street, Philadelphia, Pennsylvania.

DR. FREDERIC PALMER, JR., Department of Physics, Haverford College, Haverford, Pennsylvania.

MR. HASELTINE SMITH, 326 Walnut Street, Philadelphia, Pennsylvania.

MR. C. A. WOODBURY, E. I. du Pont de Nemours and Company, Chester, Pennsylvania.

NON-RESIDENT.

DR. ARTHUR P. TANBERG, E. I. du Pont de Nemours and Company, Henry Clay, Delaware.

ASSOCIATE.

MR. ALFRED ERNE, 5217 DeLancey Street, Philadelphia, Pennsylvania.

CHANGES OF ADDRESS.

DR. A. M. COMEY, 380 Mt. Auburn Street, Cambridge, Massachusetts.

MR. KERN DODGE, 5135 Pulaski Avenue, Germantown, Philadelphia, Pennsylvania.

MR. W. E. FLETCHER, 4609 Osage Avenue, Philadelphia, Pennsylvania.

MAJOR THOMAS H. GRIEST, The Bell Telephone Company, 261 N. Broad Street, Philadelphia, Pennsylvania.

DR. EDWARD MARBAKER, Mellon Institute, Pittsburgh, Pennsylvania.

MR. WM. H. RICHMOND, Box 226, Daytona Beach, Florida.

MR. JOHN B. RUMBOUGH, P. O. Box 2, Ashville, North Carolina.

NECROLOGY.

Prof. B. H. Hite, Morgantown, West Virginia.

LIBRARY NOTES.

PURCHASES.

ADAMS, ROGER, and others. [ed.]—Organic Syntheses. 1921.

AITCHISON, LESLIE.—Engineering Steels. 1921.

American Institute of Mining and Metallurgical Engineers.—Pyrometry. 1920.

California State Railroad Commission.—Inductive Interference. 1919.

GRIFFIN, ROGER CASTLE.—Technical Methods of Analysis. 1921.

HERING, RUDOLPH, and GREELY, SAMUEL A.—Collection and Disposal of Municipal Refuse. 1921.

HOYT, SAMUEL L.—Metallography, 2 vols. 1920-21.

HUYGENS, CHRISTIAAN.—Oeuvres Complètes, vols. 13 and 14. 1916-20.

KNECHT, EDMUND, and HIBBERT, EVA.—New Reduction Methods in Volumetric Analysis. 1918.

HOWSON, E. T., and others. [ed.]—Maintenance of Way Cyclopedia. 1921.

PORTER, J. EDWARD.—Bibliography of the Activated Sludge Process of Sewage Treatment. 1921.

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Allen Cone Company, Bulletin No. 20 on Allen Sand Tanks. El Paso, Texas, no date. (From the Company.)

Allen, John F., Company, Riveting Machines. New York City, New York, no date. (From the Company.)

Allis-Chalmers Manufacturing Company, Bulletin No. 1115 on Alternating Current Generators and Bulletin No. 1819 on Electric Hoists. Milwaukee, Wisconsin, 1921. (From the Company.)

American Gas Furnace Company, Bulletin No. 12 on Carbonizing Machines. Elizabeth, New Jersey, no date. (From the Company.)

American Society of Civil Engineers, Index to Transactions, 1867 to 1920, Transactions, vol. lxxxiv. New York City, New York, 1921. (From the Secretary.)

American Society of Heating and Ventilating Engineers, 1921 Year-book. New York City, New York, 1921. (From the Society.)

Armour Institute of Technology, General Information. Chicago, Illinois, May, 1921. (From the Institute.)

Arnessen Electric Company, Inc., Bulletin No. 471 K, Marine Electrical Equipment. New York City, New York, no date. (From the Company.)

Ashworth and Parker, Booklet on the Parker Engine. Bury, England, no date. (From the Company.)

Baker, Joseph, Sons, and Perkins, Ltd., Booklet on Baker's Patent Speed Gears. London, England, 1921. (From the Company.)

Barber-Green Company, Belt Conveyors, Self-feeding Bucket Loaders. Aurora, Illinois, 1920. (From the Company.)

Beaumont, R. H., Company, Catalogue 36, The Right Way with Ashes, and Catalogue 40, Coal and Ash Handling Systems for Boiler Houses. Philadelphia, Pennsylvania, 1921. (From the Company.)

Benjamin Electric Manufacturing Company, Catalogue No. 23 on Electrical Products. Chicago, Illinois, no date. (From the Company.)

Best, C. L., Gas Traction Company, Best Tracklayer Sixty Tractor. San Leandro, California, no date. (From the Company.)

Bigelow Company, Booklets on Water Tube Boilers and Return Tubular Boilers. New Haven, Connecticut, no date. (From the Company.)

Blanchard Machine Company, Data Book on Blanchard High-power Vertical Surface Grinder. Cambridge, Massachusetts, no date. (From the Company.)

Bridge, David, and Company, Ltd., Booklet on Gearing and Hauling Installations. London, England, no date. (From the Company.)

Brubaker, W. L., and Brothers, Catalogue No. 6 of Taps and Dies. New York City, New York, no date. (From the Company.)

Burton-Rogers Company, The Cadmium Test. Boston, Massachusetts, no date. (From the Company.)

Buxton, George E., Address on Wage Incentives and Production. Springfield, Massachusetts, October, 1921. (From the Author.)

Byers, A. M., Company, Bulletins 26, 27, 30, 32, 34, 38 and 41. Pittsburgh, Pennsylvania, 1921. (From the Company.)

Carnegie Endowment for International Peace, Year-book, 1921. Washington, District of Columbia, 1921. (From the Secretary.)

Chisholm-Moore Manufacturing Company, Catalogue 25 on Hoists, Trolleys and Cranes. Cleveland, Ohio, no date. (From the Company.)

Codd, E. J., Company, Booklet on Chain Furnace Screens. Baltimore, Maryland, no date. (From the Company.)

Consolidated Expanded Metal Companies, Booklet on Steelcrete Slab Tables, and a Handbook of Design. Braddock, Pennsylvania, no date. (From the Companies.)

Conveyors Corporation of America, Booklet, The Proof of the Pudding. Chicago, Illinois, no date. (From the Corporation.)

Council of Arts and Manufactures of the Province of Quebec, 1921-22 Catalogue of Day and Evening Classes. Montreal, Canada, 1921. (From the Council.)

Cuerpo de Ingenieros de Minas y Aguas, Anales del Congreso Nacional de la Industria Minera, Tome II, V, and VI. Lima, Peru, no date. (From the Corps of Engineers.)

Cullman Wheel Company, Catalogue No. 12 on Sprockets. Chicago, Illinois, no date. (From the Company.)

Dawnay, Archibald D., and Sons, Ltd., Handbook of Design of Constructional Steel Work. London, England, no date. (From the Company.)

Despatch Manufacturing Company, Catalogue III on Despatch Electric Ovens. Minneapolis, Minnesota, no date. (From the Company.)

Detrick, M. H., Company, Catalogue on Detrick Hagan Steam Jet Ash Conveyor. Chicago, Illinois, no date. (From the Company.)

Dorr Company, The Treatment of Sewage and Industrial Waste Waters, Bulletin No. 20. New York City, New York, 1921. (From the Company.)

Dravo Contracting Company, Bulletins 110 to 116 inclusive on Inland Waterway Harbor Floating and Terminal Equipment. New York City, New York, no date. (From the Company.)

Dunlop and Ranken, Ltd., Steel Stock Catalogue. Leeds, England, no date. (From the Company.)

Electric Storage Battery Company, Bulletin on Charging Equipment for Exide

Batteries. Philadelphia, Pennsylvania, October, 1921. (From the Company.)

Fairbanks Company, Automobile and Service Station Equipment. New York City, New York, no date. (From the Company.)

Flory, S., Manufacturing Company, Catalogue No. 33 on Capstans. Bangor, Pennsylvania, no date. (From the Company.)

Gear Grinding Company, Ltd., Booklet on Motor Car Gear Box Production. Handsworth, Birmingham, England, January, 1921. (From the Company.)

Georgetown University, General Catalogues for 1916-1917, 1919-1920 and 1920-1921. Washington, District of Columbia. (From the University.)

Gillis and Geoghegan, Folder of Pamphlets on Telescopic Hoists. New York City, New York, 1921. (From the Company.)

Goucher College, College Bulletins for April and July, 1915; April, July and August, 1916; February, 1917; August, 1918; August and December, 1919, and June and April, 1920; Directories of Alumnæ and Non-graduates, January, 1915, and February, 1918; Bulletin on War Activities, February, 1919, and Catalogues, February and August, 1920. Baltimore, Maryland. (From the College.)

Greaves-Klusman Tool Company, Pamphlets on Lathes. Cincinnati, Ohio, no date. (From the Company.)

Hadfield-Penfield Steel Company, Booklets: Fuel Oil Engines, Horizontal and Vertical Types. Bucyrus, Ohio, no date. (From the Company.)

Hardinge Company, Catalogue No. 9 of Pulverized Fuels. New York City, New York, September, 1921. (From the Company.)

Harvard University, Contributions from the Jefferson Physical Laboratory, for 1919 and 1920. Cambridge, Massachusetts, 1921. (From the University.)

Hi-Voltage Equipment Company, Bulletin No. 2 on Lightning Arresters, Choke Coils and Fuses. Cleveland, Ohio, 1921. (From the Company.)

Ingersoll-Rand Company, Handbook for Four Tool Compressor Cars and Bulletin on Air and Gas Compressors. New York City, New York, August, 1921. (From the Company.)

Institution of Automobile Engineers, Session 1920-1921, Proceedings, and Index, vols. xi-xv. London, England. (From the Institution.)

International Railway Fuel Association, Proceedings of the Twelfth Annual Convention. Chicago, Illinois, May, 1920. (From the Association.)

Irving Iron Works Company, Catalogue 3A. Long Island City, New York, 1921. (From the Company.)

Kansas State Board of Agriculture, Report No. 155 on Wheat in Kansas. Topeka, Kansas, 1921. (From the Board.)

Kearney and Trecker Company, Catalogue No. 22 of Milwaukee Milling Machines. Milwaukee, Wisconsin, no date. (From the Company.)

Kinite Company, Booklet on Kinite. Milwaukee, Wisconsin, no date. (From the Company.)

Layne and Bowler Company, Booklet on Water Supply and Turbine Pumps. Memphis, Tennessee, no date. (From the Company.)

LeBlond, R. K., Machine Tool Company, Booklets on Multi-cuttings and Multicut Lathes. Cincinnati, Ohio, 1920. (From the Company.)

Leeds and Northrup Company, Bulletin 767. Philadelphia, Pennsylvania, 1921. (From the Company.)

Lincoln Memorial University, Catalogue 1921-1922. Harrogate, Tennessee. (From the University.)

Link-belt Company, Book No. 215 on Belt Conveyors. Philadelphia, Pennsylvania, 1921. (From the Company.)

Louisiana State University, Catalogue 1921. Baton Rouge, Louisiana, May, 1921. (From the University.)

McGill University, Calendar 1920-1921. Montreal, Canada, 1920. (From the University.)

Marryat and Scott, Booklet on Lifts. London, England, 1921. (From the Company.)

Massachusetts Department of Public Utilities, Annual Report for 1920, vols. i and ii. Boston, Massachusetts, 1921. (From the Department.)

Metals Coating Company of America, The Schoop Metal Spraying Process. Philadelphia, Pennsylvania, no date. (From the Company.)

Michigan Stamping Company, Bulletin No. 10. Detroit, Michigan, 1921. (From the Company.)

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National Physical Laboratory, Report for 1920. London, England, 1921. (From the Laboratory.)

New York City Department of Health, Keep-well Leaflet No. 21. New York City, New York, no date. (From Dr. Walton Clark.)

New York Public Service Commission, Report for 1917 on Statistics of Light, Heat and Power Companies. New York City, New York, 1918. (From the Commissioners.)

Niles-Bement-Pond Company, Progress Reporter, No. 29. New York City, New York, no date. (From the Company.)

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Oberlin College, Annual Catalogue, January, 1921. Oberlin, Ohio. (From the College.)

Oliver-Barth Jack Company, Catalogue No. 1 on Jacks. Milwaukee, Wisconsin, 1921. (From the Company.)

Oxweld Acetylene Company, Oxweld Can Do It. Newark, New Jersey, no date. (From the Company.)

Parsons, C. A., and Company, Ltd., Pamphlet on End Tightened Reaction Blading. Newcastle-on-Tyne, England, 1921. (From the Company.)

Pawling and Harnischfeger Company, Bulletin No. 56X on Excavating Equipment. Milwaukee, Wisconsin, no date. (From the Company.)

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Philadelphia Department of City Transit, Annual Report for 1920. Philadelphia, Pennsylvania. (From the Department.)

Pittsburgh, Cincinnati, Chicago and St. Louis Railroad Company, Fourth Annual Report. Pittsburgh, Pennsylvania, 1920. (From the Secretary.)

Polytechnic Institute of Brooklyn, Catalogues of the College of Engineering, 1919-1922. Brooklyn, New York. (From the Institute.)

Power Specialty Company, Bulletin 300 on The Foster Superheater. Chicago, Illinois, September, 1921. (From the Company.)

Purdue University, Annual Catalogue, 1920-1921. Lafayette, Indiana, 1921. (From the University.)

Queensland Under Secretary for Mines, Annual Report for 1920. Queensland, Australia, 1921. (From the Secretary.)

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Rutgers College, Annual Catalogue 1920-1921. New Brunswick, New Jersey, 1921. (From the College.)

Ryerson, Joseph T., and Son, Bulletin 1301 on Selective Geared Head Engine Lathes. Chicago, Illinois, no date. (From the Company.)

Sanitation Corporation, Bulletin G-6 on Hydraulic and Sanitary Equipment. New York City, New York, no date. (From the Corporation.)

"S-C" Regulator Manufacturing Company, Booklet on Feed Water Regulation. Fostoria, Ohio, no date. (From the Company.)

Smith and Serrell, Bulletins Nos. 32 and 33 on Flexible Couplings. Pittsburgh, Pennsylvania, 1921. (From the Company.)

Smithsonian Institution, Annual Report of the Board of Regents. Washington, District of Columbia, 1919. (From the Institution.)

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Stanton Ironworks Company, Ltd., Booklet on The Stanton Hume Reinforced Concrete Pipe. Nottingham, England, no date. (From the Company.)

Steel City Electric Company, Catalogue No. 33. Pittsburgh, Pennsylvania, May, 1918. (From the Company.)

Sturtevant, B. F., Company, Catalogue No. 282, High Humidity Dry Kilns. Hyde Park, Boston, Massachusetts, September, 1921. (From the Company.)

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Swedish Chamber of Commerce of the United States, Sweden as Producer of Wood Goods, Pulp, Paper, Tar and other Forest-Products. New York City, New York. (From the Swedish Chamber of Commerce.)

Taylor Machine Company, Booklet on Taylor Principle Oil Engines. Chicago, Illinois, no date. (From the Company.)

United Engineering and Foundry Company, Bulletins FR and F. Pittsburgh, Pennsylvania, no date. (From the Company.)

United States Geological Survey, Professional Paper No. 123 on A Superpower System for the Region between Boston and Washington. Washington, District of Columbia, 1921. (From the Survey.)

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University of Akron, Annual Catalogue, 1917, 1918, 1920 and 1921. Akron, Ohio. (From the University.)

University of Chicago, Circular of Information, April, 1921. Chicago, Illinois. (From the University.)

University of Cincinnati, Announcement of Courses, 1921-1922. Cincinnati, Ohio. (From the University.)

University of Oklahoma, General Catalogue 1920-1921. Norman, Oklahoma, March, 1921. (From the University.)

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University of Toronto, Calendar 1920-1921. Toronto, Canada. (From the University.)

Watts Brothers, Ltd., List No. 5 of Portable Boring Machine and Booklet on Modern Woodworking Machines. Sheffield, England, no date. (From the Company.)

Western Reserve University, Reports of the President and Other Officers, 1920-1921. Cleveland, Ohio, September, 1921. (From the University.)

Westinghouse Electric and Manufacturing Company, Reprint No. 91. East Pittsburgh, Pennsylvania, no date. (From the Company.)

West Virginia University, Catalogue and Announcements 1920-1921. Morgantown, West Virginia, July, 1921. (From the University.)

Wheeler Condenser and Engineering Company, Catalogue No. 108C of Centrifugal Pumps. Carteret, New Jersey, 1921. (From the Company.)

Wilson, John H., and Company, Ltd., Catalogue 55W of Deck Machinery. London, England, 1921. (From the Company.)

Wisconsin Geological and Natural History Survey, Bulletin No. 55, Soil Survey of Northern Wisconsin and Bulletin No. 58, Geography and Economic Development of Southeastern Wisconsin. Madison, Wisconsin, 1921. (From the State Geologist.)

Wyer, Samuel S., Salient Features of Electric Cooking, Electric Hot Water Heating and Electric House Heating. Columbus, Ohio, 1921. (From the Author.)

Yale University, Report of the President, 1920-1921. New Haven, Connecticut, 1921. (From the University.)

BOOK NOTICES.

La Matière et l'Énergie. Par Louis Rougier, Docteur ès Lettres. 8vo., xi-112 pages, paper bound. Price 9 fr. 50.

This is a new edition of the essay entitled "La Matérialisation de l'Énergie" which was rendered into English by Professor Masius as "Philosophy and the New Physics." This translation was reviewed in the issue of this journal for September last. In the present volume the author discusses the principle of relativity in some paradoxical relations, such as the attribution to energy of mass, weight and structure, and the view that matter is only a particular

form of energy. The old idea of a distinction between the ponderable and the imponderable gives place to the theory of an electromagnetic field or energy, of which radiation and matter are simple modalities, and a gravitational field or Einstein space. There is a brief bibliography the items of which are about evenly distributed between German and French sources with only one English reference. Being a French book there is, of course, no index.

HENRY LEFFMANN.

INDUSTRIAL AND POWER ALCOHOL. By R. C. Farmer, O.B.E., D.Sc., etc. 18mo., 105 pages, illustrations, bibliography and index. London and New York, Sir Isaac Pitman and Sons. 2s. 6d. net.

This compact and convenient volume contains a very large amount of carefully selected information on a most important industrial problem. There is perhaps no point in our present-day industrial development in which a more serious difficulty is met than in regard to the application of ethyl alcohol to manufacturing and power uses. Its beverage relations have always been a stumbling block to allowing its free manufacture, and the procedures of denaturization have only partially solved the problem. The advantages of alcohol for power purposes, especially in portable motors, both on sea and land are numerous. It is safer in the fire risk, is practically inodorous, more cleanly than the petroleum and coal-tar hydrocarbons, and is in unlimited supply, since the vegetable substances from which it can be obtained are easily grown, while the petroleum is a natural product which may become exhausted. Moreover, alcohol is of constant composition, while gasoline is variable. The question of cost is, however, the dominating one, and so far it has not been possible to bring down the commercial production of strong alcohol to a point at which it can actively compete with the ordinary motor fuels. It is also true that the usual form of engine is not satisfactorily applicable to alcohol, and one serious drawback is the comparatively low volatility of the latter. It is stated by Doctor Farmer that it is generally difficult to start an engine with alcohol, especially in cold weather, unless a preheater is employed for the carburetor, or a small amount of volatile hydrocarbon is first used. This mechanical difficulty may, however, be overcome if other drawbacks, especially cost, disappear. The book in hand gives a long list of raw materials from which alcohol may be obtained, but the existing literature shows that upon the question of cost no definite data are available. Denatured alcohol is now selling in the American market at about 40 cents a gallon, a price which places it wholly out of competition with "gas."

HENRY LEFFMANN.

INDUSTRIAL HYDROGEN. By Hugh S. Taylor, D.Sc., Associate Professor of Physical Chemistry, Princeton University. 203 pages and index, 8vo. The Chemical Catalogue Company, Inc., New York.

This is one of the series of monographs issued under the auspices of the American Chemical Society, the general conditions of which publications have been set forth in reviews of earlier numbers. The list of subjects to be treated in the series is quite large and comprehensive. The present work maintains the high character which was set by the earlier volumes, and covers a subject

in which chemistry and engineering are closely associated, but in which the principles of physical chemistry come much into consideration. So far as book-making is concerned the book is worthy of its text.

Hydrogen exists in the free state in nature in but a limited extent although abundant in combination. Air contains but very small amounts of free hydrogen, but some natural gases are richer. The occluded gas of meteoric iron consists largely of free hydrogen. Spectroscopic research indicates the existence of large amounts of free hydrogen in the sun, but it may be that in the intensely heated exterior of the sun, all chemical combination is abolished. For many years hydrogen has been used in both research and practical work. Shortly after the invention of the hot-air balloon, hydrogen was substituted, and has been much used, although coal gas has been also much employed. The oxy-hydrogen blowpipe was for a long while the only method for getting very high temperatures, and the lime light was an extension of this action.

For the preparation of hydrogen on a moderate scale, and especially when only occasionally wanted, the action of dilute sulphuric acid on iron offered a convenient method and was much used. The simplest method is by the action of steam on heated iron. This was brought out practically first by Lavoisier, who, in a paper presented to the Academy of Sciences in 1781, described the method and apparatus.

The older industrial uses of hydrogen did not usually require a gas of high purity, nor was the cost of production so important, but the newer applications require high purity and the operating cost is of moment. Among the important modern applications are the hydrogenation of oils and the manufacture of ammonia. For the former process several million feet of hydrogen are consumed every working day in this country. Perhaps the first importance is to be attached to the application in ammonia production. The now famous Haber process which was so successfuly operated in Germany during the war has necessitated a great development of hydrogen. The production of one short ton of ammonia involves the theoretical consumption of more than 82,000 cubic feet of hydrogen. When it is borne in mind that the full operation of the Haber plants in Germany is said to have yielded considerably over a million pounds of ammonia per day, the immensity of the consumption will be appreciated. It is stated on good authority that if these synthetic processes had not been brought to the efficiency they had, the war would have ceased in 1915, as the British blockade would have cut off very soon the supply of Chile nitrates.

Doctor Taylor sets forth many other uses for commercial hydrogen, some of which are naturally the outgrowth of the cheapening of the manufacture of it, due to the attention which has been paid to the subject.

The monograph covers very thoroughly the field and presents in clear and comprehensive form the leading methods of manufacture, with discussions of the chemical, physico-chemical and physical problems involved. Thirty pages are devoted to the testing for the impurities, from which we see that though the impurities commonly present are not numerous, most of them are highly objectionable. A glance at the index of authors shows that the field has been industriously investigated by the chemists and chemical engineers of all the principal countries. Many ingenious processes have been devised, but the bulk of the book is devoted to a few standard methods, among which the direct

decomposition of steam by chemical action is taken up first. The first patent is given as dated 1861, though this was long after Lavoisier had shown the practicability of the method. Extraction of the hydrogen of water-gas by liquefaction and the electrolysis of water are also given full attention. Illustrations and diagrams are liberally used and the work constitutes a most interesting and valuable contribution to one of the comparatively recently developed fields of chemical engineering.

HENRY LEFFMANN.

THE CENTENARY VOLUME OF CHARLES GRIFFIN AND COMPANY, LTD., with a foreword by Lord Moulton, and contributions by other collaborators. 290 pages, 8vo. Charles Griffin and Company, Ltd., London.

This fine specimen of printing, with interesting essays by distinguished writers and scientists, commemorates the completion of a century of activity in the publishing business of the issuing firm. The house started in Glasgow, and was for some time publishers to the University. Griffin's Public Library was organized in that city, and a cut of the original building is given as frontispiece. Many portraits and illustrations of buildings are included. Some of these bring us back to the early days of the 19th century, in the hot youth of the western republic when George the third was king and James Monroe, president, about the time when Alexander of Russia, that curious mixture of mysticism and despotism, was trying to bring peace to the world by the Holy Alliance, a scheme that failed completely.

The individual essays relate principally to the publishing activities of the firm during the century of its existence, and the table of contents indicates how wide that field has been, though limited to books of useful and educational character. As a specimen of printing and press work it is excellent and the photogravures are in the best modern style.

HENRY LEFFMANN.

LA PHYSIQUE THÉORIQUE NOUVELLE. By Julian Pacotte, D.Sc., with a preface by Emile Borel. 8vo., 179 pages and contents. Paris, Gauthier-Villars et Cie. Paper bound, 12 francs, net.

This work comprises within moderate compass and without mathematical methods a collection of the theories which constitute the new theoretical physics. This science has for origin the electrodynamic principle of Lorentz, the defined form of that of Maxwell. The more advanced theories are due to Einstein. They relate to relativity, the energy equivalent of two material masses, the atoms of energy. Among the innumerable questions that arise from this view, two points seem particularly important. The first of these is that of the relations between continuity and non-continuity. Emile Borel has developed this subject. Riemann observes very justly that all our observations (based on the theory of the existence of rigid solid bodies) prove that space is in the mean closely approximate to the Euclidian form. These observations are less delicate than those by which we can prove that a polished metallic surface is flat. We know that in the case of the metallic surface there is only an appearance of flatness. An enlargement will bring out numerous irregularities. On a different scale, we know that the surface of the ocean is, in the mean, sensibly spherical in spite of irregularities. The second point is the

new conception that there is set forth, more and more, a theoretical physics wholly analogous, by its methods, to geometry.

The author hopes that this book will serve to direct the interests of many younger workers to theoretical physics in which the work to be accomplished is great, and requires the coöperation of the scientists of all countries, each one carrying out the labor according to his particular culture.

HENRY LEFFMANN.

A COAL MANUAL FOR SALESMEN, BUYERS AND USERS. By F. R. Wadleigh, Member, American Institute Mining and Metallurgical Engineers. 18 mo., 178 pages and index. National Coal Mining News, Cincinnati, 1921. Price $2.50.

Within very small compass this book contains a large amount of interesting and important matter. The coal question is a very important one and the householder is as deeply interested in it as the larger user. The subject matter is included under nine chapters and a bibliography. A brief allusion to history is made, and some account given of the origin of the material. General statistics of the occurrence of coal are furnished. A chapter on coke is included and practical directions as to the use of fuel in power plants. Interesting information is given as regard spontaneous combustion in stored coal. Several pages are devoted to the consideration of pulverized coal, the opinion being decidedly favorable to this form.

HENRY LEFFMANN.

LA LOI DE NEWTON EST LA LOI UNIQUE. By Max Franck. 8vo., 156 pages and contents. Paris, Gauthier-Villars et Cie.

Thoughts in regard to time and space have engaged the attention of scientists from a remote period, and Einstein's revolutionary theories have intensified modern interest in the subject. France has apparently taken the question much to heart and sharp discussion has followed the promulgation of the theory of relativity, with the result that intellectual Gaul is now divided into two parts, one hotly defending Einsteinism and the other as hotly opposing it. The present work is a contribution from the latter side, in which the author examines the mechanics of space assuming that all potential energy resides in the absolute void of the physicist, and that all matter is constituted by a unique element of inertia, mobile in the void.

The first consequence of the author's examination of the data is the confirmation of the Newtonian formula, which the announced law will give an exact interpretation, for which reason the author has chosen the specific title of his work. The theory thus applied utilizes only the ideas of space, time, force and inertia included in Euclidian geometry and in rational mechanics.

HENRY LEFFMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS, Report No. 115, Bending Moments, Envelope, and Cable Stresses in Non-Rigid Airships. By C. P. Burgess. 14 pages, illustrations, quarto. Washington, Government Printing Office, 1921.

No simple but comprehensive method of calculating the principal stresses in the envelope of a non-rigid airship has hitherto been described and published in the English language. The present report describes the theory of the calcula-

tions and the methods which are in use in the Bureau of Aeronautics, United States Navy. The principal stresses are due to the gas pressure and the unequal distribution of weight and buoyancy, and the concentrated loads from the car suspension cables.

The report deals also with the variation of tension in the car suspension cables of any type of airship, with special reference to the rigid type, due to the propeller thrust or the inclination of the airship longitudinally.

PUBLICATIONS RECEIVED.

Essai Philosophique sur les Probabilités, par Pierre-Simon Laplace. 2 vols., 16mo. Paris, Gauthier-Villars et Cie., 1921.

Memoires sur l'Electromagnétisme et l'Electrodynamique, par André-Marie Ampère. 110 pages, illustrations, 16mo. Paris, Gauthier-Villars et Cie., 1921.

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CURRENT TOPICS.

X-ray Analysis of Three Series of Alloys. MARY R. ANDREWS. (*Phys. Rev.*, Sept., 1921.)—The diffraction patterns resulting from the passage of X-rays through crystals are gradually laying bare the intimate structure of both elements and compounds. The method has now been applied in the research laboratory of the General Electric Company to the study of alloys. Fine filings of the alloy were mixed with collodion or zapon and pasted upon a thin sheet of glass. The diffraction lines produced when a narrow beam of X-rays traversed the layer were recorded photographically.

In the cases of nickel-iron alloy the structure is centered-cubic alone from pure iron up to a content of 22 per cent. nickel, from 30 to 100 per cent. nickel the structure is face-centered cubic alone. For intermediate percentages both types of structure exist in the same specimen. An interesting connection between structure and magnetic properties seems to be indicated as an outgrowth of experiments on a particular alloy entirely non-magnetic at room temperature, but showing magnetic properties after having been chilled by liquid air. After the treatment there was a distinct development of the centered-cubic structure which was wanting in the non-magnetic state. A Heusler alloy likewise gave a centered-cubic form.

Zinc-copper alloys have a far more complicated structure. There are ranges of composition where they are face-centered cubic or centered-cubic, rhombohedral or hexagonal, with combinations for for intermediate compositions.

This pioneer work opens up a new field of investigation in the important matter of alloys.

G. F. S.

The Reception of Wireless Waves on a Shielded Frame Aerial. A. A. CAMPBELL SWINTON. (*Phil. Mag.*, Oct., 1921.)—The experiments here recorded were undertaken to test a suggestion that it might be worth while to see whether direction-finding properties for wireless waves would show themselves in an arrangement made by placing a frame aerial inside of a metal tube or wire spiral open at both ends. The investigation was carried out at London using the waves from the Eiffel Tower, in Paris, with the wave-length of 2600 metres.

A wooden frame, $1\frac{1}{2} \times 1\frac{1}{2} \times 4$ feet in length, was wrapped spirally with copper wire to form the shielding tube. Within it was put the frame aerial. The latter gave as strong signals as when it was outside the tube, so long as the ends of the square wire spiral were not connected with each other. Upon connecting them, however,

the signals dropped to 50 per cent. of the former strength. The presence or absence of grids of wire, closing the ends of the tube and connected to the spiral, made no difference. Furthermore it made no difference in what direction the tube itself pointed so long as the plane of the frame pointed to Paris. Enclosing the tube, ends as well as sides, with iron wire netting reduced the strength of the signals, but wrought no change in the failure of the combination to show the direction along which the waves were coming, except in so far as the frame alone did this.

The aerial frame with the telephone receiver and other auxiliary apparatus was placed within a cube of sheet copper, connected to earth. The audible signals were conveyed to the ear outside of the cube by means of a rubber tube. The cube was left open on one side. When this open side was toward Paris and the frame properly pointed the intensity of the signals was estimated to be 5 per cent. of that given with no shielding for the frame. Upon gradually closing the open sixth side the strength of the signals diminished but never entirely ceased to be audible until the metal of the lid made contact with the metal of the rest of the cube. With the box tightly closed no signal whatever could be heard. Exactly the same results were got when the open side of the cube pointed away from Paris. Tin-foil pasted on wood acted just like a sheet of copper for the lid of the box. This calls to mind Faraday's famous room covered with tin-foil within which there were no electrostatic effects observable.

G. F. S.

Centennial of Photography.—*La Revue Française de Photographie* is preparing to celebrate the hundredth anniversary of the discovery of photography. A contributor asserts in a recent issue that the first step in the art was made by Niépce in 1822. The formal announcement of Daguerre's method was made before the Academy of Sciences by Arago in 1839, and this date has been generally regarded as the initial one, for which reason a celebration of the semi-centennial was held in 1889. Frenchmen have strong tendency to claim French initiative in every field of photographic work, and are especially antagonistic to claims made in Germany for priority, but it does appear that there is some basis for such claim, inasmuch as a German investigator did make some pictures early in the 18th century by taking advantage of this method. Other workers contributed to the early development. Charles, a Frenchman, made silhouettes in the latter part of the 18th century, and Davy and Wedgewood also obtained simple pictures in 1802. It appears that Niépce made most important advances, but his work did not attract wide attention, and it was left for Daguerre to develop an entirely new method and to place photography on a practical basis.

H. L.

Production of Furfural from Corn-cobs.—Furfural is a heterocyclic aldehyde which is used as a reagent to detect the presence of certain compounds such as indol and the bile acids. It is also used in the synthesis of certain dyes. Usually it is prepared by the distillation of bran with hydrochloric acid. F. B. LA FORGE (*Jour. Indus. Eng. Chem.*, 1921, xiii, 1024–1025) has devised a method for the production of this aldehyde by heating corn-cobs with water under pressure. The process is conducted at a temperature of 180° to 185° C. in an autoclave, which is provided with a condenser, through which the evolved vapors pass and are condensed, as the pressure is released. Several successive portions of corn-cobs may be extracted with the same portion of water; the insoluble residue of cellulose is removed from the autoclave before the next batch of cobs is added. Each batch is heated under pressure for 45 minutes. The solution obtained from the corn-cobs is heated in the autoclave for 15 minutes at the temperature stated; then the pressure is released; a volume of water equal to the volume of the condensed liquid is added to the contents of the autoclave; and the entire cycle is repeated several times. Furfural is present in, and is recovered from the condensed liquid. The yield of furfural is approximately 7.75 per cent. of the weight of the corn-cobs used. The process may be simplified by omission of the removal and saving of the cellulose; however, the latter is a valuable by-product.

J. S. H.

The Luminosity of the Night Sky.—CH. FABRY has a short article on this subject in *Scientia*. Newcomb was the first to draw attention to the matter, and said "The total quantity of light coming from the aggregate of stars may serve to control our theories of the universe. It seems possible to determine not only the total value of this emission, but also values from each part of the sky. The quantity should be considered as a constant basic value in astronomy." The problem is to determine the total emission and also the intrinsic emission of each area of the sky. Newcomb made a rude attempt in this direction.

Fabry says that, omitting some discordant results, the brilliancy of a given point in the sky seems to be constant. Different areas are not in agreement with each other, but the differences are less than might be supposed. In the Milky Way the most brilliant portions are about double the luminosity of the less brilliant. The general light of the sky is the influence that prevents us from seeing distinctly stars below the 6th magnitude. If the background was without luminosity, stars as low as the 8th magnitude could be seen. This source of the light cannot be referred to the stars which are individually indistinguishable. Several suggestions are offered as to the possible source of this general luminosity, but no experiments or observations on the subject are reported in the paper.

H. L.

Some Factors Affecting the Resistance of Sputtered Platinum Films. L. R. KOLLER. (*Phys. Rev.*, September, 1921.)—As soon as a film of the metal is formed by sputtering from the cathode its electrical resistance commences to change. If the film is kept in a high vacuum, at first the decrease is rapid, then it becomes slower and at the end of 12 hours it is negligible. In one case the initial resistance was about 1400 ohms and the final amount was one-third of this. In the freshly deposited film the resistance must consist of two parts, one the resistance of the metal itself and the other the resistance due to the contacts between the particles constituting the film. The diminution of the total resistance is ascribed to the coalescing of the particles with a consequent lessening of the contact resistance. Anything that hinders the union of the particles should make the change of resistance slower. When air is admitted to the film at first a slight rise in the resistance takes place. After this there is practically no change in the resistance. What probably takes place is this: As soon as the air comes into contact with the metal the latter becomes covered by an adsorbed layer of air, which forces the particles apart a little and thus increases the resistance. Subsequently no further coalescence of the particles can occur owing to the layer and the resistance remains constant. When the air is pumped out the aging process resumes its course. Oxygen is far more effective in modifying the decrease in resistance than are nitrogen and carbon dioxide. In this connection it was found that the sputtering process renders the platinum of both the cathode and the film active so that it causes oxygen and hydrogen to unite at room temperature.

The temperature coefficient of the films is smaller than that of the metal in one piece. The increase of temperature makes the genuine resistance greater but this change is opposed by the reduction in resistance brought about by the coalescence favored by the higher temperature.

G. F. S.

New Specific Heat Apparatus. EZER GRIFFITHS. (*Proc. Phys. Soc. London*, August 15, 1921.)—The usual methods of measuring specific heat manifestly do not apply to such substances as cork, charcoal, slag wool and diatomaceous earth, yet these are of technical importance on account of their low heat conductivity which is the very property rendering it difficult to determine the specific heat.

The substance was first reduced to a fine powder. This was then placed in a hollow aluminum cylinder until the latter was less than half full. On the inside of the cylinder were fins to stir the powder up. Besides these the cylinder contained a stationary coil, heated by the electric current, and several thermo-junctions for the measurement of temperatures. The cylinder was rotated and the current passed through the heating coil. The heat there developed goes to raise the temperature of the powder swirling through the coil and

also of the cylinder and its contents, for which a correction can be made. Loss of heat by radiation is obviated by surrounding the cylinder with a copper drum wound with a heating coil. By this means it was possible to maintain the temperatures of the drum and of the cylinder the same, so that no exchange of heat between them took place.

The temperature of the powders was raised through only fifteen degrees in order to avoid changing the moisture content during the experiment.

The following values were found for the specific heats—charcoal, 29; slag wool, 17; diatomaceous earth, 23; cork, whether slab or granulated, 43.

G. F. S.

Gas Masks for Fire Fighters.—The success of the U. S. army gas mask, which at the close of the war had been developed to a satisfactory protection against all the gases met on the battle-field, led to a hasty judgment that it might be used as a protection against the products of combustion in mines, common fires and some industrial products, but this is not the case. Some misleading statements were made by advertisers who had masks for sale. Experience showed that the army masks do not protect against the ordinary products of combustion, which are largely carbon dioxide and monoxide. Neither of these was an important ingredient in the offensive war gases, yet they are both capable of causing suffocation. Moreover, in a notable percentage of cases, the suffocating effect is not due to the introduction of any poisonous gas, but to the diminution of oxygen, and it is obvious that no mask can protect against such condition.

Technical Paper No. 248 of the U. S. Bureau of Mines, a pamphlet of over fifty pages, gives the results of many experiments and investigations for ascertaining the proper material for masks for miners and firemen. In some cases, indeed, army masks have served a good purpose, one instance being a fire in a waste-paper plant. The army mask gives no protection against ammonia, which is important in view of disasters at refrigerating plants, and the frequency with which small refrigerating plants are attached to other industrial establishments. The gases commonly encountered in fires and other accidents in civil life have been carefully studied by the authors of the bulletin, Messrs. Fieldner, Katz and Kinney. The composition of the most important absorbents is given, but it appears that no satisfactory absorbent for carbon monoxide is yet obtainable. Some progress has been made in the matter, however, and it is expected that a satisfactory absorbent may before long be found. This gas is one of the most dangerous in the list, because it is a common product of imperfect or choked combustion and is also present in large amount in common illuminating gas. In fact, it is responsible for more deaths in civil life than all other gases combined.

H. L.

The Muscle Shoals Plant.—This great plant located on the Tennessee River was erected as a war industry for the purpose of nitrogen fixation. The portion designated as No. 1 was arranged to operate a modified Haber process, while a much larger installation, No. 2, operated the cyanamid method. No. 1 had not been carried beyond the experimental stage when the war closed, and further work was discontinued. No. 2 is complete and has a capacity of 110,000 tons of ammonium nitrate per year. All work, however, has been suspended as well as on the great dam, which was to utilize the water power of the stream. It is stated that the dam as planned will furnish water enough to develop 600,000 horsepower. The Mississippi Valley Association, at its meeting in May last, appointed a committee to bring to public notice the facts about this plant, and the committee has lately issued a report in pamphlet form with illustrations. The following are some of the conclusions reached:

That two nitrate plants, of large capacity, well built at great expense, and required for national defense are standing idle.

That these plants can be made a profitable investment and a benefit to agriculture if cheap power is available.

That this cheap power can be furnished only by the dam, now awaiting completion.

That in its present condition the dam blocks navigation on the Tennessee River.

That the work done to date has been well done, but will certainly be damaged if abandoned in its present condition.

That additional delay means only a constantly increasing loss to the Government.

That a relatively small additional cost will bring to fruition a great enterprise, and add an important factor to the development of our country.

That the completion of this enterprise is one of the most important factors before us at this time and in accord with the declaration of principles of our Association which calls for the development of agriculture, of industry, of finance, and of transportation.

In view of the fact that the Government can not transfer its right to manufacture nitrate by the cyanamid process to others than the patentee, a government controlled corporation or corporations should be established to operate both the hydro-electric power and the nitrate plants, preference being given to agriculture, but always reserving the right to resume control and operation in event of war.

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